SUPPORT FOR EDUCATIONAL TECHNOLOGY R & D: THE FEDERAL ROLE

by

Charles Blaschke
Beverly Hunter
Andrew Zucker

Educational Turnkey Systems, Inc.

September 30, 1987

This document was prepared under a contract with the Office of Technology Assessment, Congress of the United States, for the assessment, *Power On: New Tools for Teaching and Learning*. The conclusions are those of the authors. The document does not necessarily reflect the analytical findings of OTA, the Advisory Panel, or the Technology Assessment Board.

J952-27.

Acknowledgments

This report was prepared by three coinvestigators, Charles Blaschke of Education TURNKEY Systems, Inc., Beverly Hunter of Targeted Learning Corporation, and Andrew Zucker of SRI International, with the assistance of many other individuals.

Regarding Department of Defense funding and institutional arrangements, we gratefully acknowledge the assistance, cooperation, and insights of Dr. Dexter Fletcher, Institute for Defense Analyses; Dr. Marshall Farr, former Director of the Office of Naval Research; Mr. Frank Moses, DDR&E; and Dr. Byars Vicino who maintained and operated the DoD MATRIS system, a model reporting system on education and training research and development.

Within the U. S. Department of Education, Dr. Arthur Sheekey provided us with access to computer printouts on ED research and development support related to computer-based education, and Dr. Frank Withrow, Team Leader for Education Technology, assisted us greatly. Dr. Andrew Molnar of the National Science Foundation provided us with a wealth of insights and information on R&D funding programs and strategies across agencies. Other individuals who shared their time and knowledge are noted in Appendix A. Without the assistance of these individuals, this project could not have been completed.

Office of Technology Assessment staff provided useful insights and comments throughout the project. Dr. Linda Roberts' personal attention, editorial comments, constructive criticism, and persistence assisted us enormously in identifying critical events and factors through three decades of R&D support for education technology.

To all of you, thank you! Of course, we accept responsibility for the contents of this report.

Charles Blaschke
Beverly Hunter
Andrew Zucker

TABLE OF CONTENTS

EXECUTIVE SUMMARY vi

I. INTRODUCTION 1

II. HISTORY OF SUPPORT: 1960-1987 4

A. Context for R&D Support for Education Technology: 1960-70 4

1. Government Policies 4
2. The Education Technology Industry 5
3. Educational Technology R&D Issues During the Sixties 7

a. Cost-Effectiveness 7
b. Demonstrations 7
c. Institutional Arrangements in the Sixties 8
d. Technology R&D Personnel Shortage in the Sixties 9
e. Control 10

B. U. S. Office of Education and U. S. Department of Education 10

1. Office of Education: 1961-70 10

a. Context 11
b. Total USOE Spending During the Sixties 11

2. The Years 1971-1980 at USOE/ED 13

a. Context 13
b. Total USOE/ED Spending in the Seventies 14
c. Research and Development at USOE: 1971-80 14

3. The Department of Education: 1981 to the Present 17

a. Context 17
b. Total ED Spending: 1981-1987 17
c. Research and Development at ED: 1981-1987 18

4. Lessons Learned from USOE/ED Experiences 21

C. National Science Foundation 23

1. 1968-76: The Context of Computing in Schools 25
2. 1968-76: NSF Research and Development Funding 25
3. 1968-76: NSF Contributions and Impact 28
4. 1977-83: The Context 28
5. 1977-83: NSF Funding 29
6. 1977-83: NSF Contributions and Impact 31
7. 1984-87: The Context 32
8. 1984-87: NSF Funding 33
9. Lessons Learned from NSF Experiences 34

TABLE OF CONTENTS
(Continued)

II. D. Department of Defense 35

1. 1960-70: Laying the Foundation 36

a. R&D Support by Service 36
b. Elements of the Foundation for Future CAI 39
c. Other DoD Contributions: 1960-70 40

2. 1970-80: Emergence of CMI and Simulation - Military 41

a. U. S. Army 41
b. U. S. Navy 42
c. U. S. Air Force 43

3. Other DoD Projects: 1960-80 43

a. University of Illinois: PLATO 44
b. Army 1500 System Evaluation Electronic Training 45
c. Advanced Instructional Systems (AIS) 45

4. 1980 to Present: Intelligent CAI and Related Technologies 46

a. U. S. Army 46
b. U. S. Navy 52
c. U. S. Air Force 52

5. DoD Funding History for R&D Support of Technology: Summary and Analysis 53

a. Comparisons of DoD Funding: 1976-79 with 1985-89 54

III. ILLUSTRATIVE R&D PROGRAMS 60

A. Instructional Systems Approach (ISA) Computer-Based Education in the Air Force: 1950-1961 61

1. Chronology of Major Events, Activities and Impact 61
2. Findings and Their Relationship to Project HINDSIGHT 66

a. Time Lag 66
b. Communication 66
c. Funding 67
d. Environment 67

B. Rocky's Boots and The Learning Company 67

1. Origin and Creation of Advanced Learning Technology, Inc. 68
2. Award of the NSF-NIE Grant Leads to Commercial Success 68
3. Lessons Learned 71

a. Royalty and Copyright Policy 71
b. High Payoff 72
c. Interagency Cooperation 73

TABLE OF CONTENTS
(Continued)

III. C. Office of Economic Opportunity: Contributions but Missed Opportunities 73

1. Job Corps 74
2. Community Action Programs (CAP) Research, Training and Demonstrations 75
3. Closing Comment 76

D. Defense Advanced Research Projects Agency (DARPA): Mission, Money, Maximum Flexibility, and Management 77

1. Factors Contributing to DARPA's Success 78

a. Mission 78
b. Money 79
c. Maximum Flexibility 79
d. Management 80

E. Education Department/Office of Special Education Programs: Catalytic, Multifaceted Support for Technology in Special Educ. 81

1. Brief History 81
2. Current Program 82
3. Contributing Factors 86

a. Leadership 86
b. Legislative Authority 86
c. Strategic Planning 87
d. Institutional Arrangements 87
e. Procurement 91
f. Funding 93

F. LOGO: Federal R&D to Adoption -- A Lengthy Process 93

1. Historical Events in Development and Dissemination of LOGO 93
2. Lessons Learned 99

G. Technology Transfer from DoD to Civilian Education Applications: Mixed Results 106

1. Formal Technology Transfer Involving Federal Agencies 106
2. Informal Initiatives 108

IV. FACTORS CONTRIBUTING TO SUCCESSFUL FEDERAL RESEARCH AND DEVELOPMENT FUNDING FOR EDUCATIONAL TECHNOLOGY 110

A. Funding 111
B. Leadership 113
C. Strategic Planning for Innovation 114
D. Administration of R&D Programs 117

TABLE OF CONTENTS
(Continued)

IV.	D.	1.	Internal Reporting and Coordination	118
		2.	External Communications	118
		3.	Management Styles	119
		4.	Staff Roles and Continuity	119
		5.	Organizational Climate	120
	E.		Procurement Processes	121
		1.	Instruments	121
		2.	Solicitation Process	122
		3.	Length of the Procurement Process	123
		4.	Review Criteria	123
	F.		Summary: Factors Contributing to Successful Federal R&D Funding for Educational Technology	124
V.			POLICY RECOMMENDATIONS	125
	A.		Chnaging Context and Issues in the Eighties	125
		1.	Role of Industry	125
		2.	Public Policy Issues	126
	B.		Recommendations	127
		1.	Legislative	128
		2.	Executive Administration	129
			a. Leadership	129
			b. Program Administration	130
			c. Staff Continuity	130
			d. Procurement Process	130
References				132
Bibliography				136
Appendix A				137

EXECUTIVE SUMMARY

This study examines the history of the United States Federal Government support for education technology research and development. The time period examined is 1960 to 1987. The purpose is to provide background for policy decisions with regard to future roles and funding levels for Federal support of research and development in this field. The report identifies funding levels for several civilian and military Federal agencies over this time period; nature of programs and projects supported; six case studies of illustrative R&D programs; factors contributing to successful Federal research and development funding; and policy recommendations.

FUNDING LEVELS

Estimated funding levels by decade for research and development in educational technology aimed primarily at elementary and secondary school levels are shown for the U. S. Office of Education/Department of Education and for the Science Education Directorate of the National Science Foundation in Table 1. Similar figures for research and development in military training technology are shown in Table 2. Since different sources provide different figures, an upper and lower range is shown. The basis for these estimates is explained in the body of the report.

Table 1

ESTIMATED TOTAL USOE/ED/NSF FEDERAL FUNDING FOR RESEARCH AND DEVELOPMENT FOR EDUCATIONAL TECHNOLOGY BY DECADE

	1961-1970	1971-1980	1981-1987
USOE/ED	$20,000,000	$50,000,000	$130,000,000
NSF (Elementary/Secondary)	5,000,000	15,000,000	22,000,000
Total	$25,000,000	$65,000,000	$152,000,000
Adjusted for Inflation (1967 Dollars)		$38,200,000	$ 49,200,000
Average Annual Funding	$ 2,500,000	$ 3,820,000	$ 7,030,000

Table 2

ESTIMATED RANGE OF DoD FUNDING FOR EDUCATION AND TRAINING TECHNOLOGY RESEARCH AND DEVELOPMENT BY DECADE

	1971-1980	1981-1987
DoD	$745,360,000	$1,212,700,000
Adjusted for Inflation (1967 dollars)	$424,730,000	$ 390,440,000
Average Annual Funding	$ 42,470,000	$ 55,780,000

The amounts spent on Federal R&D in educational technology for civilian education have been less than .5 percent of the total Federal education expenditures; DoD funding of education and training R&D has been about .5 percent of total DoD RDT&E expenditures.

The amounts spent on research and development in educational technology are much smaller than the total amounts spent by the Federal government on educational technology in general. This is because the majority of the projects supported are demonstrations or operation, not research and development. (See Chapter II.)

NATURE OF WORK SUPPORTED

"Technology" is any systematic treatment of an art or application of a science. Thus, "educational technology" encompasses a very wide range of methodologies, hardware, software, systems, and know-how. The purpose of research and development for technology is to improve the general state-of-art and understanding of a technology or its application. Federal projects and programs have focused on such wide-ranging technologies as:

- methodologies for teaching, testing, and developing artificial intelligence;
- hardware such as television, computers, special devices for the handicapped;

- software such as instructional computer programs, authoring systems, artificial intelligence programs;
- systems such as closed captioning systems for the deaf, computer-assisted instruction systems, intelligent tutoring systems; and
- know-how such as how to evaluate innovations and how to apply findings from cognitive science to instruction.

The majority of the R&D programs and projects supported by the Federal Government over the past three decades have been focused on taking advantage of new developments in hardware, software and know-how from the computer industry, and applying these to help solve existing problems in education such as inequitable access to educational opportunities. A much smaller proportion of the programs (primarily in military training) have focused on strategic areas such as artificial intelligence or anticipated long-range skill needs in the high-technology work place (e.g., weapons systems).

With some important exceptions, most of the programs in the civilian agencies have been of fairly short duration -- on the order of one to five years, and most of the projects relatively small funding -- on the order of $100,000 to $200,000. The military programs have been longer in duration and larger in scope.

MAJOR CONTRIBUTIONS

While state and local education agencies have the authority and responsibility for education in the United States, these agencies do not engage in very much research and development activity. State and local agencies are increasing their budgets for technology, but they are not performing a major research and development role, although the state role is increasing somewhat through consortia and other arrangements.

Federal R&D has contributed in many different ways to the state-of-art in educational technology:

- Methodologies: Systematic methods for developing instruction, often referred to as ISD, were developed initially in military training R&D in the 1960s. These methods have had major influence on

instructional development activities in all educational and training settings.

- Hardware: Civilian educational technology research does not usually focus on development of new hardware. Significant exceptions have included special devices for the handicapped, such as the Kurzweil reading machine and other special computer interfaces for physically handicapped individuals.

- Software: Many kinds of software now in common use in education have their origins in Federal R&D programs. For example, many authoring systems have been developed as part of R&D projects. Authoring systems are important for reducing the cost of developing interactive computer programs, particularly instructional programs.

- Systems: Although most major technology-based systems for learning and teaching have been developed for military training, a few such systems for civilian education have been supported primarily through Federal R&D. A major example is PLATO, which has been supported by both the military and the civilian agencies since 1960. PLATO and its progeny have been used by millions of students and teachers in a wide variety of settings throughout the world to learn just about any subject imaginable.

- Know-How: Myriad kinds of know-how have resulted from Federal R&D projects. Three examples include evaluation of innovations; application of cognitive science to learning in specific disciplines; design of effective learner-machine interaction.

- New Technology-Related Skills for Students and Teachers: Over the past few years, millions of students and teachers have acquired technology-related skills such as computer programming. Federally supported research and development provided much of the software, conceptual frameworks, and curriculum models upon which subsequent materials and methodologies for training and education were based. Examples include several projects to identify computer literacy needs supported by the NSF in the early and mid-1970s, and development of LOGO (see case study in Chapter III).

- New Models for Instructional Delivery: Sesame Street and other educational television programs have contributed to the education of millions of children throughout the world, and have demonstrated the power of technology to aid in delivery of instruction.

- Model Computer Applications for Learning: A great variety of computer applications now commercially available and commonly used in the schools have their roots in model programs developed with Federal R&D funds. Examples include microcomputer-based laboratory instrumentation for elementary and secondary science labs; instructional simulations in science and social science; economic modeling tools; career counseling programs; curriculum data bases; LOGO; basic skills drill and practice programs; computer-managed instruction programs; interactive videodisc programs.

- New Businesses: Several private businesses serving the education community began with Federal research and development grants. An example, The Learning Company, is discussed in Chapter III.

- New Institutional Arrangements: Successful application of educational technologies has sometimes required invention of new institutional arrangements. For example, the Office of Special Education Programs/Department of Education (ED/OSEP) created a variety of institutional arrangements with research and development groups and hardware and software companies in order to develop, evaluate, produce, distribute and facilitate the use of high quality and relevant media and technology to meet educational needs of handicapped children.

- R&D Personnel: The Federal government -- particularly DoD and DARPA -- has played a major role in building the cadre of quality personnel needed to advance the field of educational technology R&D.

MISSED OPPORTUNITIES

While Federal R&D has been essential to the establishment of the field of educational technology and to the current state-of-the-art, an examination of the historical context for this work points out several ways in which more, or different, Federal support might have satisfied other needs of the educational system. The reader may infer some of these missed opportunities from Chapter II: History of Support. Some of these include the following:

- Basic Research on Learning and Teaching with Technology, Especially Computers. As described in Chapter II, the majority of the funding in the Department of Education (and USOE) for educational technology in the 1960s and 1970s was for projects to demonstrate the benefits or effectiveness of particular technology applications, rather than to achieve a deeper understanding about how children think and learn in high-technology environments. Hence, by the late 1970s and 1980s when schools were purchasing hundreds of thousands of microcomputers, there was less scientific basis for making decisions about the appropriate or beneficial uses of hardware and software than there could have been if the earlier R&D had included more fundamental research on learning.

- Long-Term Strategic Programs. As described in Chapter II, neither the Department of Education nor the National Science Foundation has been able to sustain strategic programs in technology (with important exceptions such as the work by Children's Television Workshop and the multifaceted approach taken by the Media Services/Technology Program of OSEP and OERI in the early 1980s. Rarely have these agencies been able to bring together all the facets of educational change needed -- including basic research, hardware and software development,

curriculum revision, teacher education, testing and evaluation methods -- in order to achieve innovation.

- Types of Computer Use in Learning and Teaching. Of the hundreds of computer-related R&D projects supported by the Department of Education/USOE over the past three decades, the vast majority used the computer primarily for drill and practice in basic skills. The result is that today, the evaluation literature on the effectiveness of computers in instruction is predominantly for these teaching machine applications. In comparison, little systematic research and evaluation exists for other kinds of applications in learning and teaching, such as the use of computer-based tools to aid in writing, science or social science inquiry, mathematical modeling and problem solving, or development of higher-order thinking skills. Thus, educational policy makers who now need evaluation data to make decisions about future investments in computer technology have a skewed base of literature to which they can refer.

- Transfer and Application of Military R&D to Civilian Education. Military investment in educational technology R&D vastly overshadows the investment made by civilian agencies. As discussed in Chapter III, numerous attempts have been made over the years to find both formal and informal ways to transfer the methods, equipment, software, and know-how generated from this military work to civilian education. For example, Secretary of Defense McNamara and other high-level DoD officials argued in the mid-1960s that the DoD could be a test bed for advanced development and testing of technologies, providing opportunities for spinoffs into the civilian sector. Formal interdepartmental initiatives to facilitate technology transfer from military to civilian education have not worked, due to factors discussed in Chapter III. Some transfer of technology from DoD to civilian education environments has taken place through informal mechanisms such as collaborative planning among agencies for large projects such as PLATO, military agency support for national conferences such as those supported by the Office of Naval Research, military support of graduate students who later seek employment in civilian education research, and through transfer of DoD R&D staff to civilian agencies, R&D centers, and private firms.

- Curriculum Reform. Despite the facts that nearly every school in America uses computers and other technological devices in some way in learning and teaching, that thousands of educational computer programs, instructional films and video programs are available on the market, and that today's students need to be prepared for an increasingly technological and information-based work place, nevertheless the curriculum, as reflected in textbooks and tests, have not been altered in any fundamental way as a result of these technological developments. Textbook publishers and standardized test publishers have still been unable to take the financial risk inherent in such reform. Federal R&D programs have not, in general, taken on the challenge of assisting State and local education agencies in reassessing curricula in light of the information revolution and technology, except in the case of courses specifically technology-dependent such as computer science.

FUNDING FACTORS CONTRIBUTING TO SUCCESSFUL FEDERAL RESEARCH AND DEVELOPMENT IN EDUCATIONAL TECHNOLOGY

Chapter IV discusses six characteristics of funding for successful research and development in educational technology: amount of funding, continuity of support, interagency collaboration, cooperation with industry, flexibility of funding, and research mission. The nature of technology-based R&D is such that inadequate funding amounts for work requiring advanced equipment and sophisticated, multidisciplinary staffing results in only minor or partial advances, whereas a relatively small amount of dollars spent at the right time with the right people for a conference can make a major contribution to the state-of-the-art. On the other hand, large amounts of funding for development that lacks a solid theoretical or empirical foundation can be relatively ineffective. Thus, funding levels need to be appropriate to the type of research or development being undertaken at a given point in time under particular conditions.

As important as the adequacy and appropriateness of funding is the continuity of support for a program or project. Major innovations require eight to 15 years from their inception to reach commercial or widespread application in schools (see the case study on LOGO in Chapter III). One of the ways successful program managers have been able to sustain funding for promising research is by collaborating with their counterparts in other agencies. Some of the most successful projects have resulted, for example, from joint efforts by the National Science Foundation and the Department of Education. During periods when budgets for civilian education have been cut, NSF program managers have protected their most important projects by seeking support from military agencies or DARPA. Another mechanism successful program mangers have found for sustaining adequate funding is to establish cooperative "in-kind" funding with industry.

Flexible funding authority is another important characteristic of funding for educational technology innovation. To address key problems for which it is well suited, an agency must identify trends, events and circumstances that make its involvement timely and must be able to act on these opportunities.

LEADERSHIP FACTORS CONTRIBUTING TO SUCCESSFUL R&D

In the agencies examined in this study, productive R&D has been associated with leadership at either executive or program management levels or both. At high levels, leadership has encouraged the risk taking that is essential in this inherently high-risk field of research and development. At program manager and division levels, successful work has benefited from continuing efforts by dedicated civil servants with vision, persistence and an emphasis on quality. These individuals view their jobs as shaping the direction of the emerging field and identifying strategic opportunities for innovation and improvement of learning and teaching through technology. They persist in supporting these thematic lines of research and development through the vicissitudes of funding authority, political and organization change, and the changing technology base.

STRATEGIC PLANNING FOR INNOVATION

Support for cutting edge work in an emerging field such as educational technology requires strategic thinking, coordinating many dimensions of the work. Factors involved in strategic planning discussed in Chapter IV include:

- strategic goals;
- a coherent set of initiatives, aimed at improving content and methods of curriculum, professional capacity of educators, and functioning of the overall educational system;
- a long-range view of innovation;
- creation of a cadre of people within the research community who can perform the work;
- a concentration of work in the key areas;
- an appropriate equipment base;
- training and professional development of practitioners; and
- appropriately timed basic research, applied research, development, demonstration and evaluation work.

The case study on the Office of Special Education Programs in Chapter III provides an example of such multifaceted efforts.

FACTORS IN ADMINISTRATION OF R&D PROGRAMS

Research and development in educational technology has certain characteristics, such as its multidisciplinary nature, the rapidly changing underlying technology, the complex institutional nature of American education, and the inherently high-risk nature of the work. These characteristics result in the need for certain characteristics in the administration of the programs. Five of these are discussed in Chapter IV:

- effective internal communications, reporting and coordination;
- effective external communications with performers, the R&D community, users, private industry, and Congressional staff;
- flexibility in management, enabling decisions to be made quickly;
- staff ingredients: highly competent professional, long-term civil servants mixed with short-term expert "rotators" from the field; conditions for hiring and keeping highly qualified staff who perform as professionals in the field, such as encouragement to attend professional meetings and site visits; and
- organizational climate and relationship between the R&D agency and its parent organization.

FACTORS IN PROCUREMENT PROCESSES

Procurement processes used by agencies are their primary formal means of establishing relationships with the R&D community. Quality research and development cannot be procured in the same way that weapons systems are procured. The mechanisms must make it possible to attract the most highly qualified performers and enable them to carry out the work in a creative, sustained manner. While the issues are usually very complex, there appear to be certain elements in the procurement process associated with successful R&D programs. Elements discussed in Chapter IV include:

- flexibility to use different types of procurement instruments for different types of performers and types of R&D;

- a mix of formal and informal solicitation methods that provide for collaborative shaping of proposals among agency staff and potential performers while attracting the most highly qualified performers;

- efficient procurement processes that minimize technological obsolescence of projects; and

- review mechanisms and criteria that make it possible to fund high-risk, multidisciplinary projects that may involve new paradigms or threaten existing infrastructures in education.

I. INTRODUCTION

In response to a request from the House Committee on Education and Labor, the Office of Technology Assessment (OTA) has initiated a study entitled "Education Technology: An Assessment of Practice and Potential". Given the phenomenal growth of technology -- particularly microcomputers -- in schools during the last decade and the substantial amount of Federal funds used by schools to purchase hardware and software, the Committee instructed OTA to explore a number of policy issues, one of which is the Federal role in supporting research and development for education technology.

The purpose of this study is to describe Federal support of research and development for education technology. The specific objectives are to:

- examine the history of Federal funding and other direct support of education technology research and development;
- identify the impact of funding levels and alternative institutional arrangements through a series of substudies of illustrative R&D programs; and
- develop a set of recommendations in the context of the study's findings.

The approach taken by the project team was straightforward. First, extant documentation -- reports, correspondence, studies, etc. -- were collected and reviewed. Second, key individuals directly involved in the major R&D programs supporting education technology during the last three decades were interviewed or asked for official information and documents, along with personal papers, etc. Third, R&D programs and projects were identified; the characteristics of these programs which have contributed to their success (or lack thereof) were gleaned from documents and interviews with officials from sponsoring agencies and others associated with the programs. Fourth, as information was compiled and reviewed, the staff conducted independent analyses, compared findings (particularly across successful programs), and arrived at consensus regarding factors contributing to successful policy. And last, policy recommendations were developed.

The primary sources of information from the relevant agencies were:

- Department of Education: previous studies of Federal support for education technology R&D -- particularly computer-assisted instruction -- conducted by Greyson, Molnar, and Zucker, and recent ED compilations of funding support.

- National Science Foundation: official documents, reports, etc. prepared since the creation of the Office of Computer Activities (1967) and information and personal papers prepared by key agency staff such as Dr. Andrew Molnar; and

- Department of Defense: published and unpublished papers by Dr. Dexter Fletcher (now with the Institute for Defense Analysis); unpublished papers, correspondence, and studies by Charles Blaschke; budget and related documents prepared by officials within DDR&E; and a special analysis conducted at the request of the project team by Dr. Byars Vicino, relying upon the Manpower and Training Research Information Systems (MATRIS), a "success story" itself in reporting of DoD funding for personnel training and research.

The information on CAI support during the 1960s relied on both published and unpublished studies by a member of the project team and personal correspondence with policy makers in the emerging education technology industry. Generally, information about the 1970s relied heavily on previous studies and other, rather scant, documentation, while information on the 1980s came from official documents, budgets, etc.

Because the study was conducted in less than two months, with an allocation of less than 30 person days (a limitation in itself), the findings are less comprehensive than they could have been. These limitations include:

- Funding levels, in many instances, are based upon estimates which are probably more accurate and reliable than official documents and budgets. For example, within DoD, attempts were made to separate technology-related research and development in education and training from non-technology-based R&D. NSF estimates were used to separate K-12 R&D from higher education activities.

- Many of the agency officials were more than willing not only to describe the history of their R&D programs, but also to share with us their perceptions and biases about factors contributing to overall success. Care was taken by the project team to identify and minimize the effects of such biases during analyses.

- The selection of illustrative programs was influenced by the initial analysis of factors contributing to general program success. After a

preliminary analysis of general findings, the project team identified -- through a consensus-building process -- the specific programs to be analyzed in depth. Where possible, individuals responsible for or knowledgeable about such programs had opportunities to review the "case studies".

II. HISTORY OF SUPPORT: 1960-1987

This chapter summarizes the amounts of funding and nature of educational technology research and development supported by the Federal government over the past three decades. The chapter first characterizes the context in which this R&D work began in the 1960s. It then presents summaries for: (a) the U.S. Office of Education and U.S. Department of Education; (b) the National Science Foundation; and (c) the Department of Defense.

A. CONTEXT FOR R&D SUPPORT FOR EDUCATION TECHNOLOGY: 1960-70

Federal support for R&D in education technology during the 1960s can only be explained in the context of the 1960s -- changing government policies, industry's posture, and the major educational R&D issues related to technology.

1. Government Policies

The two wars, Vietnam and Poverty, had mutually reinforcing, as well as conflicting, influences on technology support by various agencies. The general Department of Defense R&D cutbacks (both in-house and contracted) encouraged many defense contractors to consider civilian applications of defense technology and "systems approaches" in education and other social service areas. Passage of the Elementary and Secondary Education Act of 1965 and the creation of the Office of Economic Opportunity further encouraged industrial "diversification". President Johnson's policy of "Creative Federalism" relied heavily on technology-based industry support and initiatives:

> There are numerous cases where the technology is already at hand but is awaiting a demonstration of its practicality and the creation of a market. One contribution the Federal government can make is in helping to overcome reluctance to accepting promising innovations by making possible their demonstration and evaluation."[1]

Toward the end of the sixties, however, the Vietnam build-up had not only severely constrained R&D activities within the civilian agencies but also forced R&D agencies within the defense sector to focus only on short-term development efforts which could contribute directly to the Vietnam initiative (e.g., simulations for training helicopter pilots). As a result, legitimizing R&D support for technology, particularly computer-assisted instruction (CAI), was difficult.

While civilian support for computer-assisted instruction increased dramatically during the mid-sixties, it tapered off during the late sixties just as dramatically because of budget constraints and unreal expectations among policy makers in the government and industry about the technology potential.

2. The Education Technology Industry

The education technology "industry", particularly firms developing computer-assisted instruction services and systems, were concerned primarily with the creation of educational markets for its products and services. In response to President Johnson's policy statement, the vice president of one of the largest firms developing CAI systems stated:

> "Either we develop what education leaders tell us they need or we attempt to develop quality goods and services, hoping that the system will change its practices so that a market will be created. Rather than asking whether or not industry will provide the catalytic role in introducing change, I would like to know how serious the Federal government is in providing us with the opportunity to realize this role. Very simply put, it is the responsibility of the Federal government to ensure that dollars flow from Washington in such a way that it is profitable in the long run for industry to move in a direction which serves rather than undermines the public interest in education."[2]

The use of DoD, OEO, and other Federal programs as demonstration sites to create markets was recognized by many corporate officials, particularly those who previously served in high-level positions in several Federal agencies (e.g., Eugene Fubini (DoD to IBM), Edward Katzenbach (DoD to Raytheon), John Nesbitt (OEO to SRA), Frank Keppel (USOE to General Learning Corporation),

among others). During the mid-sixties, however, a large number of mergers, acquisitions, and joint ventures occurred involving electronics firms, publishers, and systems software companies (e.g., IBM/SRA, General Electric/Silver Burdett, Raytheon/D.C. Heath).

Interviews and personal communications with key officials in many of these and other companies indicated different corporate philosophies about creating a market for computer-assisted instruction (see Exhibit 1) and about the technology-related issues of the 1960s.

Exhibit 1

DIFFERING CORPORATE PERSPECTIVES: 1960s

"Let's use existing hardware, terminal and other, and concentrate our efforts on the development of functional software and curricula."

"We must find laboratory type actual training programs in which we can experiment and at the same time develop software and curricula through action research 'feedback'; once we have learned enough about the learning process, we can then concentrate on the type of hardware configurations which will be the most compatible and conducive to learning; we cannot expect much hard data from the university R&D centers."

"Cautious urgency is the word; yet, we must choose the consumer to whom we sell our almost 'debugged' equipment in order to minimize any marketing black eyes while the market is being created."

"The firms will have to be rather cooperative, at first letting each other develop specific curricular and functional software which is compatible with each others pieces of hardware; after the market is created then we will be in cut-throat competition."

"In order to increase the probability of amortization of costly R&D, the initial market must be a 'hedge' yet in itself large enough to show economy of the CAI system. The military training program is a good hedge for curricula development in that there exist several civilian counterparts such as junior colleges, technical schools, and in-house industrial programs. Also the unit size of the various programs are larger than most others."

Source: Background Paper for CTEP, "Training Method Study", Office of the Secretary of Defense, Manpower, 1966.

---

3. Educational Technology R&D Issues During the Sixties

Implicit in the brief overview of Federal policy and industry context are a number of educational R&D issues and factors which influenced the nature of R&D support for education technology during the 1960s.

a. Cost-Effectiveness

Throughout the agencies, particularly within DoD, instructional technologies including computer-based instruction and related development had to be justified in terms of cost-effectiveness. Within the DoD, this emphasis had both positive and negative effects on R&D support. Most of the CAI support was funded through Operations and Maintenance (O&M) line items (rather than basic or applied research) and resulted in some CAI applications that indeed proved to be cost-effective. For example, the use of the IBM 1500 System in electronics training in the Signal Corps was found to be cost-effective as instructional time was reduced by eleven percent. On the other hand, cost-effective criteria constrained many applied research efforts and forced some underground. In both the U. S. Office of Education and the Office of Economic Opportunity, many computer-assisted instruction projects were funded under the guise of cost-effectiveness when, in fact, the performers perceived them as basic research and development projects. Premature or inappropriate application of cost-effectiveness criterion in most projects resulted in findings that CAI was not cost-effective.

b. Demonstrations

As noted earlier, Federal and corporate officials, including the President, promoted the need to demonstrate technology applications, including computer-assisted instruction, in operational settings. Demonstration programs were established in the U. S. Office of Education (e.g., ESEA Title III) and the Office of Economic Opportunity (e.g., Communication Action Program; Educational Technology Research, Development, and Demonstration Programs). The availability of relatively large amounts of funding within USOE and OEO resulted in many hastily funded projects without adequate planning and often with conflicting political goals. However, it was quickly

discovered that much research on learning and teaching would be needed before effective applications could be demonstrated. In response to perceived need, a line item (6.3) was created within DoD for education and training to provide opportunities for advanced development and testing. As Secretary McNamara stated in his 1965 directive:

> "After reviewing last year's $3 billion education and training program, I am struck by the absence of any significant research and development activity to improve our effectiveness in this area. I am also aware that there is social science research and development directed toward improving our education and training capabilities. A greater effort should be made to apply recently-developed modern training technique and education concepts to existing Defense training and education programs.
>
> I therefore wish you to establish a line item in the budget for educational research and development. These funds are to be used primarily on specific projects directed toward the improvement of existing Defense Department education and training programs."[3]

As noted below, however, few services took advantage of this opportunity for a number of reasons, including the fear of failure and jeopardies to careers. While each agency could point to successful demonstration programs of CAI, the effect of these programs on creating a market was limited.

c. Institutional Arrangements in the Sixties

Institutional arrangements between Federal agencies sponsoring R&D and performers had a significant impact on R&D during the 1960s. Relative to other agencies, DoD used contracts more than grants for research, and particularly for development, and Operations & Maintenance (O&M)-supported computer-based instructional projects and systems. In the mid sixties, slightly more than 50 percent of personnel research funds were allocated to nonprofits and universities, ten percent to industry, and the remainder to in-house civilian and military laboratories and units for "learning and training".[4] The units within OEO which supported education technology research and development and/or operational programs using technology (e.g., the Job Corps) relied heavily on contracts rather than grants, except in situations where performers were universities. Procurement procedures for OEO (e.g., Armed Services Procurement Regulations) were established by a team of

military officers and DoD civilians assigned to OEO during its creation in 1964 (i.e., the Yarmolinski Task Force). The audit agency for OEO was the Defense Contract Audit Agency. Many of the R&D performers during this time period were firms or individuals associated with firms involved in computer-assisted instruction or were defense contractors selected to operate Job Corps centers (Litton Industries, Westinghouse Learning Company, Science Research Associates-IBM, and Philco-Ford, among others). The Office of Education, through its Bureau of Research, was not allowed to contract with industry until 1967. However, a number of firms with CAI programs, hardware, and other components were associated with OE-supported R&D university performers (e.g., CCC and Stanford University) throughout this period. The National Science Foundation, whose computer-related activities received impetus in the late sixties, relied almost exclusively on grants rather than contracts and supported university-based performers.

d. Technology R&D Personnel Shortage in the Sixties

A critical issue during the 1960s was the availability of quality R&D personnel to monitor and perform R&D on education technology and particularly computer-based instruction. In 1963, there were approximately 2,000 performers of education and training R&D related to technology. By 1966, this number jumped to more than 6,000. Like the "scientists" and "engineers" in the defense research and engineering build-up during the fifties, the increase in dollars through ESEA and OEO enticed many less qualified individuals into this field.[5] A similar problem existed with the availability of trained staff to monitor and direct R&D projects, especially in agencies expanding the use of contracts as procurement instruments.

Perhaps the greatest contribution of the military to R&D support for technology during the sixties was skilled staff. For example, according to Klaus, after the establishment of the "instructional systems development" teams of the Air Training Command in the early sixties, its first graduating class of 352 individuals doubled the number of skilled instructional programmers in the country at that time.[6] Many of these graduates were directly involved in R&D support for CAI during the mid-1960s within the Job Corps.

e. Control

Attempts to develop partnerships between the emerging education technology industry and Federal agencies (such as DoD, USOE, and OEO) raised concern among proponents of local control in education. Several corporate officials such as Keppel,[7] who had previously served in Federal agencies, recognized the importance of local control and the need for industry to adapt its products to meet local needs. On the other hand, some educators felt that defense contractor activity in the education market (incorporating such concepts such as program budgeting, systems approach, and cost-effectiveness), in conjunction with "reform-minded" leadership within USOE and OEO, could result, as a natural consequence, in greater centralization.[8]

B. U. S. OFFICE OF EDUCATION AND U. S. DEPARTMENT OF EDUCATION

The U. S. Office of Education (USOE) during the 1960s was part of the Department of Health, Education and Welfare (HEW). In 1965, Congress passed the Elementary and Secondary Education Act (ESEA) which vastly increased the scope and magnitude of Federal education assistance (from $375 million in 1958 to $4.2 billion a decade later), and resulted in the wholesale reorganization of USOE.[9] The Education Division of HEW grew still larger when the National Institute of Education (NIE) was created in 1972. The U. S. Department of Education was formed in 1980, consisting almost entirely of the Education Division of HEW (along with several programs from the NSF, and other small pieces).

The discussion below is divided into three parts. These present information corresponding to the decades of the sixties, the seventies and the eighties.

1. Office of Education: 1961-70

This section summarizes the context for USOE funding in the sixties, the amounts spent, the nature of the work supported, and notable projects.

a. Context

The 1960s witnessed rapid growth in Federal education spending, an increased interest in computers, and -- not surprisingly -- a growing belief that computer-based education was an appropriate target for Federal expenditures (e.g., to improve education for the disadvantaged). During the 1960s, time sharing was invented. This made it possible for many users to use a single computer simultaneously, and thereby made it economically feasible to consider having students access an otherwise impossibly expensive computer. USOE spending for computer-assisted instruction reached its zenith in the late 1960s; according to Grayson, more than $46 million for computer-related projects was being spent by USOE in 1968 alone.[10] Another indicator of the interest in computer-based education during the sixties was the President's cience Advisory Committee's recommendation that the NSF and the Office of Education jointly investigate the use of computers in secondary schools -- and President Johnson urged that these agencies should become more involved. The growing Federal interest was matched by activity in the schools: by the end of the decade, computers were being used in 34 percent of secondary schools primarily in administrative and computer science programs. While school computer use was low by current standards, computers at that time were very expensive and required a much greater commitment of resources than computers do today. This was an era of pioneering and concomitant excitement.

b. Total USOE Spending During the Sixties

Spending by USOE on computer-related projects was concentrated in three major sources: the Bureau of Research, aid for compensatory education (Title I of ESEA), and aid for supplementary centers and services (Title III of ESEA). Very little money was spent on computer-related instruction during the 1960s by the Bureau of Education for the Handicapped. While many other legislative authorities were the source for some computer-related projects, total expenditures from these authorities was small.[11] Uncertainty surrounds expenditure data for computer-related projects from each legislative source.

Historical documents providing funding data for the sixties (primarily those by Grayson and Molnar) are not always in agreement (as is illustrated in

the section that follows), and resolving each of the differences with certainty is not possible. (In general, Grayson's estimates are much higher than Molnar's.) Nonetheless, a reasonable estimate of spending during the sixties would be as follows.

Total spending on elementary/secondary computer-related projects from 1961 to 1970 was about $45 million. Of this amount, roughly $20 million was for research and development. Examples of expenditures other than R&D included:

- about $2 million spent by the Title I program for computers; and
- roughly $23 million spent by the Title III program.

With millions of dollars in R&D funds available each year, the diversity of projects supported by the Bureau of Research was great, and included, in addition to basic and applied research and development, demonstrations and some dissemination efforts. However, according to one Associate Commissioner of Education, until 1967 dissemination was "one of the weakest points in the Office of Education research program".[12] What changed then was the addition of new regional educational laboratories which were intended to demonstrate and disseminate the products of educational research and development. A total for 1966 - 1970 of about $4 million seems a reasonable estimate for the computer-related projects of the labs. The largest of the laboratory projects, at over $1 million, was for developing a real-time student monitoring system to aid teachers in individualized instruction --which is a development project, not a dissemination project.

One of the best known of the computer-related projects supported by USOE in the sixties was the development of instructional materials for elementary school children, especially culturally deprived children, by Professors Suppes and Atkinson at Stanford. This work grew into the Computer Curriculum Corporation; later the efficacy of the materials was tested during the 1970s by the Educational Testing Service. The Stanford computers in California were able to serve students as far away as Kentucky and Mississippi, via telecommunications -- itself a powerful demonstration of

technology -- including the unusual fact that the computers were used for more than eight hours per day. The drill-and-practice format of most of their material is still considered effective as one technique in teaching basic skills, especially arithmetic. An unusual financial feature of the project was the use of Title III funds, which were awarded to states and localities for services, to supplement the direct support made available to Stanford for research and development.

Several full-length, computer-based courses were developed with USOE funds; however, these were aimed at the postsecondary level. An example is the New York Institute of Technology project to develop an economics course at the Naval Academy.[13] Several such courses were used at a few secondary schools.

During the sixties, USOE also funded several significant R&D projects involving video technology. One such project (under Title VII) was Wilbur Schramm's research comparing conventional teaching and video presentations. Schramm concluded that in many situations they were about equally good. Another award helped to establish a video clearinghouse/center, the National Instructional Television Center, at Indiana University; current work by the Agency for Instructional Technology under Edward Cohen, the original project director, is a direct outgrowth of the original grant. The USOE Education Broadcast Facilities Program also began in 1963 to make awards to improve the capacity of public radio and television stations in the U. S. -- an important complement to video R&D.

2. The Years 1971-1980 at USOE/ED

a. Context

The increasing expense of the Vietnam War and the priorities of a new administration, together with a realization that computer-assisted instruction would be neither a quick fix nor an inexpensive one, led USOE expenditures for computer-related projects to slow down beginning in the late sixties, and continuing into the seventies. At the same time, many of the educational technology projects of the newly-created National Institute of Education

(which replaced the Bureau of Research in USOE) were focused on television, satellites, and other technologies; few focused on computers. However, some of these few computer-related projects had an important impact.

b. Total USOE/ED Spending in the Seventies

Total spending for computer-related projects is difficult to estimate for this period due to the large number of programs, the fact that the Federal government required little reporting by states and localities receiving formula funds, and the increasing use of computers on a routine basis (for research, record-keeping, and cataloging, as well as for instruction) in many projects not mainly focused on computers or other technology.

A rough estimate for elementary/secondary computer-related projects during this decade is $200 million. Of that amount, about $50 million was for R&D, including demonstration projects.[14]

Examples of estimated computer-related spending for items other than research and development include:

- about $120 million spent by Title I;
- about $7 million spent by Titles III and IV-C; and
- about $17 million spent by NDEA Titles III and IV-B.

c. Research and Development at USOE: 1971-1980

During the seventies, the Department spent far more on research and development (primarily the latter) relating to television than it did on computer-related R&D. Development of television programming alone cost $130 million (for Sesame Street, Electric Company, and many other series), whereas in the preceding decade only a small amount had been spent on television (for Sesame Street). In the seventies, R&D on educational uses of computers was eclipsed by R&D on educational uses of television. Given that the delivery system for television was in place (at least in the home), in contrast to the situation for computers which was still a technology in its early stages, this strategy made some sense.

One factor that becomes apparent is that the Department, and those receiving its awards, increasingly were applying basic computer hardware to a variety of new and challenging applications, including speech synthesis, print recognition, decoding of coded video signals, etc. The resulting devices might not appear to be computers, but in effect that is what they were. Of course, similar trends were apparent throughout society, as programmable calculators, children's "learning aids" and other chip-based devices made their appearance.

There were a great many significant R&D projects -- both large and small -- supported by USOE and ED during the seventies. Some of the most noteworthy are highlighted here.

Closed captioning of television became a reality in 1980, after about a decade of R&D supported by HEW and the Corporation for Public Broadcasting.

The Educational Telecommunications for Alaska project provided the scattered and often small Alaskan schools with electronic mail, computer-assisted instruction, and other services via microcomputers.

Beginning in 1974, the Bureau of Education for the Handicapped (BEH) began funding the National Instructional Materials Information System (NIMIS) to provide special education staff in schools with a computerized data-base on instructional materials for the handicapped. The project later continued under the National Information Center for Special Education Materials (NICSEM).

In 1971 the Bureau for Education of the Handicapped began funding the OPTACON for the blind, a device which produces "images" of printed letters using small, raised, vibrating wires. After development was complete, millions of additional dollars were invested in dissemination of the device.

Research and dissemination funds were also provided by ED for the Kurzweil reading machine, another device for the blind, which scans text and a synthesized voice reads the text aloud.

From 1969 to 1973, BEH funded Stanford University to investigate reading and math CAI with deaf and hearing impaired students.

The Department funded two demonstrations of the use of electronic mail for communication with the deaf. One demonstration permitted use of a standard TTY, using the Baudot code, in addition to computer terminals based on ASCII.

In 1976, the National Institute of Education began funding a five-year evaluation of the use of computer-assisted instruction in the Los Angeles public schools. The CAI in use was that of the Computer Curriculum Corporation, which had its origins in earlier USOE and NSF investments. Educational Testing Service carried out the evaluation, which included rigorous control groups, and showed that some CAI used as little as ten minutes per day can produce very significant achievement gains.

Several software development contracts were awarded under the short-lived authority for improving basic skills through technology. Both the mathematics materials (produced by Ohio State University) and the reading materials (produced by WICAT) were commercially distributed. Under the same authority, a planning guide was developed for use by school superintendents, school board members, and administrators who are faced with decisions concerning the acquisition and the effective utilization of technology in schools, notably microcomputers.

During this period, the Department began supporting the Northwest Regional Educational Laboratory's project to review educational microcomputer software. MicroSift, as the project was known, distributed its reviews electronically and on paper. Also during this period (1980), the Department began supporting "Voyage of the Mimi", a multimedia science/mathematics television series with supporting computer software.

The National Institute of Education supported a study of the implementation of microcomputer programs in schools in three different U. S. cities. The Institute also published the report of a preliminary study of the use of "automated dictionaries" in education.

3. The Department of Education: 1981 to the Present

a. Context

The microcomputer revolution gained some momentum in the late 1970s, but it was not until the 1980s that it took off. The number of machines available in both homes and schools grew very rapidly. Many of the states assumed an important leadership role in introducing computers in schools (e.g., through legislative and budgetary actions -- see Section IV).

Some extremely interesting computer projects were supported by the Department of Education in the early 1980s, including a number which monitored and studies computer use, some which disseminated pertinent information about educational uses of technology, and others which developed new and imaginative applications for education. The Secretary of Education initiated what he called a "Technology Initiative", and spoke often of the need for educators to make intelligent use of computers and other electronic technologies. It was not surprising that many of the comments of Secretary Bell, as a former Chief State School Officer, were directed to those at the state level. However, Bell's successor, Secretary Bennett, de-emphasized computers, and the climate in the Department, reflected partly in the declining number of new grants involving computers, shifted significantly.

b. Total ED Spending: 1981-1987

Total spending is more difficult to estimate than in either of the preceding decades. More programs supported computer projects than in the past, including programs for bilingual education, vocational education, and the Secretary's Discretionary Fund, in addition to more familiar programs from the 1970s such as educational research (e.g., the National Institute of Education), special education, and compensatory education (Chapter 1). The Reagan administration's major legislative victory in elementary and secondary education, the Chapter 2 block grant to states and localities, became a significant source of funds (hundreds of millions of dollars) for districts to purchase computer hardware and software. The multiplicity of sources,

combined with ED's very limited ability to sort its own projects by topics, creates real difficulties in tracking computer expenditures over time.

A rough estimate of total ED spending for elementary/secondary computer-related projects during this period is about $810 million. (This amounts to $1.2 billion if extrapolated to 1990.) So-called formula funding to states and localities amounts for the bulk of this, including:

- Chapter 1 has supplied about $175 million for computers and related expenditures (according to studies by TALMIS and Education TURNKEY Systems).[15,16]

- Chapter 2 and its predecessor programs provided about $510 million. A study of the Chapter 2 education block grant by SRI International (SRI),, in collaboration with Policy Studies Associates, focused on the third year of implementation, 1984-85. The SRI study showed that support for computer applications has been the most popular activity under Chapter 2, accounting for 30 percent of all local expenditures under the block grant.[17] In 1984-85, 72 percent of the nation's schools used Chapter 2 for computer-related purchases (compared to only 19 percent which used antecedent Federal funding for such purchases).

A much smaller amount of funding has been used for research and development projects, as described in the following section.

c. Research and Development at ED: 1981-1987

Based on the available data, we estimate that ED has spent about $129 million on computer-related research and development during this period, including funds for dissemination.[18] In comparison with the preceding decade, the rate of spending for R&D related to computers has about tripled (in nominal dollars). This substantial increase reflects increases in the size and number of projects and in the increasing number of different offices in the Department with substantial R&D investments in computers for education.

At the same time, the rate of R&D expenditure is estimated to have declined by about 30 percent between the periods 1981-83 and 1984-87. One reason for this decline is that it reflects the changing priorities of the ED leadership. In the field of computer-related R&D, these reductions during

recent years were especially notable in the obligations of the Office of Educational Research and Improvement (OERI), which is the office least bound by legislative mandates (e.g., for the handicapped, or for post-secondary education) and most easily responsive to general priorities in elementary/secondary education established by the Secretary and Assistant Secretary. According to a recent computer printout listing OERI technology projects supported since 1980, it is striking to observe how many of these projects were supported in the early 1980s and how many fewer have been started since 1983.

Another change is in R&D projects of long duration. In the seventies, ED supported quite a few projects lasting five or more years, including: the evaluation of CAI in Los Angeles; development of closed captioning of television; the Kurzweil reader, and the OPTACON; and establishment of the NIMIS and NICSEM data bases. During the eighties, it is difficult to identify as many comparable products. "Voyage of the Mimi" (a television series with accompanying computer software) is one; long-term support for the new Educational Technology Center is another. A large variety of notable R&D projects have been supported since 1980.

In 1983, for the first time, the Department conceived and funded a research and development center exclusively focused on educational technology. Harvard University, together with a consortium of other institutions, was selected as the contractor for the award. Activities of the center have been wide-ranging, involving television and videodisc, as well as computers. The $7.7 million award supports activities through 1988, focusing primarily on science and mathematics.

Many other of the R&D centers and the regional educational laboratories focused some resources on computers, and continue to do so. Examples include: microcomputer programs developed at the Learning Research and Development Center (LRDC) for teaching introductory physics; performing research to determine if existing microcomputers could remediate basic skills deficiencies of secondary school students in the Appalachian Region; basic research at LRDC on social processes in small groups, and how they affect

children's learning; reviews of microcomputer software, collected under the name MicroSIFT.

New projects were conducted under the Basic Skills-Technology authority during this period. These included: development of an integrated piece of software for teaching writing in the early grades; and, experimentation with the use of interactive videodiscs and computers in the elementary schools.

Under the same authority, a series of teleconferences, videotapes, and print materials were used to provide technical assistance to State and local education agencies as they established technology programs for basic skills in school systems. This was Project BEST (Basic Education Skills through Technology), which was followed by Project SLATE, which assisted state legislators and other policy makers develop state-level plans for technology use. A portion of these activities could be considered applied research and development.

Under Secretary Bell, the National Diffusion Network (which helps local districts disseminate validated educational practices) created for the first time a special focus on the implementation of technology in schools, the NDN Lighthouse Schools in technology. In addition to these, NDN supported other exemplary technology projects, as well.

During this time period the Department, and the NSF, received programs from a grantee, Ann Piestrup, which were to become the cornerstone of a successful new company, The Learning Company. A separate case study has been prepared on this subject.

The Department supported "The Voyage of the Mimi", a multimedia science and mathematics program. This was the first time ED supported development of computer software for schools to accompany a television series. (Other TV series receiving support included "3-2-1 Contact!" and "Square One TV".)

A very large number of conferences, commissioned papers, surveys, and studies were supported during this period. For example: the Center for Education Statistics conducted two surveys of school districts' acquisition of

computers; the Department held a conference on software piracy and software quality; papers were commissioned on computers in rural districts; and several studies of software needs and opportunities in specific fields were commissioned.

A number of scholarly research studies were supported, including: the demands and cognitive consequences of learning to program; neuropsychology assessment and training of reading CAI for learning disabled students. In addition, a number of quality issues papers were developed by ED/NIE in-house staff and consultants and through ED-sponsored conferences and symposia.

The Department implemented the Congressionally-mandated Small Business Innovation Research (SBIR) program. Many of the projects under the program involved computers, such as: to use microcomputers for data acquisition in secondary laboratory science courses; to develop an automated IEP system; to design numerous software interfaces for aids and devices; and to develop several authoring systems for instructional software.

Software was developed for use with students whose primary language was not English. For example, a project in Seattle was funded to develop a CAI program to teach U. S. history to recent Southeast Asian immigrant children.

4. Lessons Learned from USOE/ED Experiences

Leadership and continuity are needed if support of computers in education is to succeed. There have been many instances in USOE/ED where support was needed for five to ten years; without that continuity, the project or program could not achieve success. Special Education Programs have been one area in which such continuity has been notable.

The leadership of Secretary Bell during the early 1980s was significant, and produced specific large-scale projects (e.g., the Educational Technology Center) which otherwise might not have been supported. It also made it possible for people in many agencies (e.g., National Institute of Education, NDN) to support smaller programs and projects involving technology (e.g., the NIE-NSF competition for improving mathematics using computers) which, while

not requiring Secretarial approval, nonetheless were much more viable in an atmosphere of general support for such ideas. The sharp reduction in funding for computer-related projects (approximately 30 percent) after Bell left reflects, in part, the effect of changing Secretarial priorities. Bell consulted widely with top members of the technology industry in a series of invitational meetings held at ED. He also launched a "Technology Initiative" which garnered considerable publicity.

. An adequate legislative and organizational base for educational technology is also important. USOE and ED had this for a time. However, largely as a by-product of efforts aimed at quite different goals, the Congress, in the Education Consolidation and Improvement Act of 1981, eliminated a number of ED's specific funding authorities for educational technology, including the Basic Skills Technology legislation and the general authority to support educational television, which had been part of the Commissioner's and then the Secretary's Discretionary Fund. In addition, the new law eliminated a former requirement that established an administrative unit to house technology. The effect was to reduce the funds earmarked for technology and force technology to compete (e.g., in the Discretionary Fund) with many different priorities. Added to this was the reorganization of OERI in 1985, which effected the elimination of OERI's strong administrative base for educational technology. Educational technology in ED is more splintered now than it used to be, especially in OERI, the office with the most general mandate to improve elementary and secondary education.

Appropriate staff expertise in educational technology and in related matters (including the disciplines taught in school) is necessary for an effective ED program on computers in education. Within the past six years or so there has been a steady exodus of highly qualified persons from ED, several of whom have joined DoD to work on related technology programs. Again, OERI, with its general "improvement" mandate, has been especially affected.

Rights and royalties policies have an effect upon the use of materials developed with ED funds. Once, rights to materials developed with USOE funds were in the public domain. In the late sixties, this policy was changed during negotiations on the Sesame Street project: program-related income

could be used for purposes related to the grant; otherwise, the money was to be returned to the Treasury. In FY 1983, an entirely new program created by Congress, the Small Business Innovation Research (SBIR) program, was implemented by ED and other agencies. SBIR is designed to accelerate the commercialization of new devices developed under government support, and it provides uniform rights policies across Federal agencies -- for that program only. In light of changing technologies (see, for example, the case study on Rocky's Boots) and a changing legislative climate, it seems wise for ED, as for other agencies, to conduct periodic reviews of rights and royalties policies to assure that they are accomplished (with the bulk of their programs) what is intended.

One change which the SBIR program has brought about in ED is an increase in the number of profit-making firms receiving awards. Otherwise, for computer-related R&D, USOE and ED have almost exclusively funded universities, laboratories, school districts, and other nonprofits. Even in recent years, the cumulative amount of funding for nonprofits far exceeds the amount awarded to small businesses through SBIR (less than $10 million since its creation). ED's best program managers have learned how to use grants, contracts, and cooperative agreements to accomplish a great deal, especially with nonprofits. This includes, in some cases, use of interagency agreements.

C. NATIONAL SCIENCE FOUNDATION

NSF funding for research and development in educational technologies began in 1968 with the establishment of the Office of Computing Activities, in response to President Johnson's request for programs to encourage computer use in schools. This separate office reported directly to the Director of NSF. In 1972, the education-oriented activities of the Office of Computing Activities were transferred to the Science Education Directorate, where they have remained since that time.

During the 19-year period from 1968 to 1987, NSF funding for research and development targeted towards technological innovation in education has been modest and fluctuating. Exhibit 2 shows the total amounts for the Directorate for Science and Engineering Education (SEE) and educational

technology R&D respectively. The amounts for educational technology R&D are based on rough estimates of the proportion targeted to elementary and secondary education. It should be noted that NSF's focus has traditionally been on higher education. Elementary/secondary education has been a relatively small component.

Exhibit 2

NATIONAL SCIENCE FOUNDATION SUPPORT
FOR RESEARCH AND DEVELOPMENT OF EDUCATIONAL TECHNOLOGY
IN ELEMENTARY AND SECONDARY EDUCATION

YEAR	TECHNOLOGY IN ELEM. & SEC. SCIENCE EDUCATION	SCIENCE EDUCATION TOTAL	TECHNOLOGY PERCENT OF SCIENCE ED.
1968	1,700,000[1]	134,456,000	1.3
1969	1,700,000[1]	115,238,000	1.5
1970	1,700,000[1]	120,177,000	1.4
1971	1,700,000[1]	98,810,000	1.7
1972	1,600,000[2]	93,729,000	1.7
1973	1,200,000[2]	62,234,000	1.9
1974	1,400,000[2]	80,709,000	1.7
1975	1,200,000[2]	74,033,000	1.6
1976	600,000[2]	62,481,000	.96
1977	1,600,000[3]	74,260,000	2.2
1978	1,600,000[3]	73,860,000	2.2
1979	1,933,000[4]	79,970,000	2.4
1980	1,933,000[4]	77,190,000	2.5
1981	1,933,000[4]	70,660,000	2.7
1982	-	20,900,000	-
1983	-	16,090,000	-
1984	4,510,000[5]	54,426,000	8.3
1985	9,170,000[5]	81,933,000	11.2
1986	6,860,000[5]	82,237,000	8.3

Notes:

[1] - 10% of OCA for elementary and secondary education.
[2] - 20% of CIE and TIE for elementary and secondary education.
[3] - 15% of DISE and RISE.
[4] - 15% of DISE and RISE + $333,000 joint program with NIE.
[5] - 20% of IMD + 100% of AAT + $500,000 per year for RTL.

The following description of NSF funding is divided into three time periods -- 1968 to 1976; 1977 to 1983; and 1984 to 1987. These time periods

correspond to three "eras" in NSF funding: 1968-76, in which NSF had programs specifically targeted to educational technology; 1977-83, which it did not have such programs; and 1984-87 in which educational technology research has resurfaced as a specific programmatic effort.

1. 1968-76: The Context of Computing in Schools

The late 1960s and early 1970s were a period of rapid growth of computing activities in colleges, universities and secondary schools. In 1963 colleges and universities were spending approximately 51 million dollars a year for computing. By 1974, the estimated yearly expenditure was around $650 million. Between the years 1963 and 1974, it is estimated that colleges and universities spent close to four billion dollars on computing with the result being that all major universities and most colleges by 1975 provided computing services to some of their faculty and students through local facilities or through access to off-campus facilities. In 1970 a national survey of secondary schools found that 34 percent of the schools had access to a computer for administrative or instructional purposes, with only 12.9 percent of that total using it primarily for instructional purposes.[19] By 1975, over half (58.2 percent) of the secondary schools in the U.S. had computers and 26 percent of those used them at least partly for instructional purposes.[20] This was a near doubling in the number of computer users in secondary schools in a five year period. Only about three to five percent of the funding for instructional computing was from Federal funds. It is clear that Federal R&D played a small role in secondary school computer use during this time.

2. 1968-76: NSF Research and Development Funding

From 1968 to 1976 the National Science Foundation had several programs specifically aimed at research and development of technology-based innovations for education. It is very difficult to isolate the elementary and secondary school applications. Based on a sampling of project abstracts for these programs, approximately ten to 15 percent of the funding was for projects specifically targeted to elementary and secondary school applications of technology. The others would be for undergraduate, graduate, or multilevel application.

NSF support for research and development in educational technology began in the period from 1968 to 1972 with the Office of Computing Activities' support of university and college regional computing networks. In fiscal year 1968, ten regional computing networks were inaugurated and in FY 69 five additional regional experiments were established. By 1969, the regional networks included 12 major universities, 116 participating colleges, and 27 secondary schools in 21 states.; CONDUIT, a project to encourage transfer of computer-based learning materials and related expertise from one university to another; and projects aimed at furthering expertise in the use of computers in specific disciplines, such as the Commission on College Physics. The Huntington Two project was supported for development of educational packages based on computer simulations for high school biology, physics and social studies. NSF support was also initiated for work in mathematics and computer literacy. The development of what later became LOGO was initiated with a grant to Wallace Feurzeig of Bolt, Beranek & Newman to create a new programming language "so simple that it can be taught to second graders". Grants were made to Patrick Suppes of Stanford University in fiscal years 1968 and 1969 to study the effect of CAI on teaching programming and data processing concepts to 80 inner-city secondary school students. The Foundation also tried a new funding approach to strengthen a few major centers to promote longer range basic research in instructional technology. Three centers at the University of Pittsburgh, Stanford University and the University of Texas were funded. Altogether six grants in computer-based instructional technology were made in fiscal year 1969 with total support about $1.2 million.

In fiscal year 1969 the Office of Computing Activities made 194 awards obligating $17 million. The amount awarded averaged approximately 50 percent of funds requested. Awards were made to 153 institutions in 39 states and the District of Columbia. Seventeen awards were made for projects involving precollege education. Of the $17 million granted 96 percent was awarded to educational institutions or consortia, and four percent was awarded to non-academic institutions.

In 1972, the educationally oriented technology work that had begun in the Office of Computing Activities was moved to the Science Education

Directorate where the work was supported under the Computing Activities in Education program. The move to the Science Education Directorate caused a shift in focus from exploiting technology to supporting existing structures within education. The new program called Computing Activities in Education survived for two years, from 1972 to 1973, and spent approximately $7.5 million per year. The program continued support for such work as that of Seymour Papert on LOGO with elementary school children and problem solving at MIT and Project CONDUIT work with regional computing networks. Funding also began for the two major computer-assisted instruction projects, PLATO IV and its plasma display panel development under the direction of Donald Bitzer at the University of Illinois, and TICCIT under the direction John Volk at the MITRE Corporation. Over a period of five years, PLATO received $7.8 million in NSF funding. Work began in 1973 at the University of Pittsburgh by Thomas Dwyer on Soloworks, a computer based high school mathematics laboratory. A small pilot effort to provide computer literacy curricula for secondary schools was also initiated during this time.

From 1974 to 1976 NSF's support for research and development in educational technology decreased each year, from $7 million in 1974, to $5.9 million in 1975, to $2.9 million in 1976. This corresponded with decreases in overall NSF science education support. The work was supported under the Technological Innovation in Education (TIE) program. Development of the PLATO IV system of CAI continued in preparation for a two-year, large-scale field test and evaluation involving thousands of students widely scattered geographically, using a single large computer system. Development and field-testing of the TICCIT system continued. Development and field-test of the PLANIT machine-independent system of CAI was completed during fiscal year 1973. Research continued at Stanford for elementary reading and mathematics, including providing CAI to American Indians in New Mexico. Other supported studies in 1973 included the examination of various communication technologies such as broadband two-way cable systems, specialized common carriers, stationary satellite, and optical communications links, with a view to assessing their potential for various nonconventional educational telecommunication services. Other projects initiated during this time include Robert Tinker's work with laboratory instrumentation connected to

microcomputers for science education and Alfred Bork's work at the University of California at Irvine on computer graphics in learning.

3. 1968-76: NSF Contributions and Impact

Despite the relatively low level of overall funding for research and development in educational technology during this period and the even smaller level of work directed specifically toward elementary and secondary education, NSF support made important and lasting contributions to the developing state-of-the-art. Seminal work in the use of computers as tools for learning and teaching in mathematics and scientific disciplines was begun during this period with NSF support, and a considerable amount of dissemination of ideas and materials was accomplished through NSF-supported conferences such as the Conferences on Computers in the Undergraduate Curriculum (CCUC), regional networks and dissemination projects such as CONDUIT. As of 1973, out of 2,750 computer programs developed for educational purposes in the U.S., over 800 had been supported in part by the NSF.[21]

Nearly all of the technological tools, pedagogies, and methodologies now widely used in education had their instructional origins in these early NSF projects -- telecommunications and computer networks; graphics; programming languages for instruction such as LOGO which is now in half the elementary schools in the U.S.; laboratory instrumentation; instructional simulations; interactive dialogues; economics modeling and gaming; social science data analysis; interactive videodisc; career counseling; and computer literacy for educators.

4. 1977-83: The Context

The period from 1977 to 1983 was a time of rapid growth in educational institutions' use of computers. Elementary, secondary, colleges and universities were acquiring microcomputers at a very rapid rate. By January, 1983, 85 percent of all high schools, 77 percent of all junior-senior combinations, and 68 percent of all middle and junior high schools had one or more microcomputers. The corresponding figure for elementary schools rose to 42 percent for the same period.[22] This period is often referred to as the

grassroots revolution in the schools. Due to the availability of low-cost microcomputers, teachers by the thousands and students by the millions began using computers for the first time.

5. 1977-83: NSF Funding

From 1977 to 1983 the NSF had no program specifically targeted to research and development in technological innovations in education. From 1977 to 1981 educational technology research and development was supported in the context of the DISE (Development in Science Education) and RISE (Research in Science Education) programs. In 1981 the Science Education Directorate was disbanded by President Reagan with the agreement of the National Science Board.

From FY1977 to 1981 FYDISE had a total funding of $36 million and RISE had $19 million during the same period -- for a total of $55 million over five years. It is difficult to state what proportion of these funds were used for technology-oriented research and development, since they were not specifically targeted for that purpose. Fifteen percent, or $8.25 million could reasonably be attributed to technology-oriented projects during that period -- an average of about $1.6 million per year. In 1979 DISE issued a special solicitation for proposals to design, build and demonstrate an interactive computer-controlled videodisc system for science education. Alfred Bork's work at the University of California/Irvine was supported to teach reasoning skills to junior high school students using computers and to study individual and group behavior in computer-based learning environments. New applied mathematics techniques (such as dynamic programming, queuing theory, and graph theory) using the PLATO system, were introduced into the school curriculum. Seminal work by James Fey at the University of Maryland on the implications of microelectronic technology for secondary school mathematics curricula was supported. Computer literacy guides for elementary and junior high school teachers were developed by Beverly Hunter at the Human Resources Research Organization (HumRRO) to show teachers how to integrate computer-based tools into the regular curriculum. Work at the Minnesota Educational Computing Consortium (MECC) was supported to study computer literacy in schools. Ann Piestrup of what became The Learning Company was supported to develop early

childhood learning programs such as Juggles' Rainbow and Rocky's Boots. Elliot Soloway's work on misconceptions of novice computer programmers was supported by the RISE program.

In addition, approximately $1 million was spent on a joint funding effort with NIE for materials development in precollege mathematics using computers in 1979-81. For example, materials were developed to train students' skills in spatial visualization and orientation, using computer graphics. There was also a small but important program of research on cognitive processes and the structure of knowledge from 1978-1980 ($1 million) of which 40 percent was used to support research of Herbert Simon at Carnegie Mellon University on cognitive processes and the structure of knowledge in physics and algebra, involving the building of computer simulations models of expert problem solver performance; work by Lauren Resnick at LRDC at University of Pittsburgh on invention and understanding in the acquisition of computational skills, involving computer simulation of individuals' understanding of arithmetic at given points in their development; and research by Patrick Suppes at Standord University on process models of basic arithmetic skills; research by John Anderson at Carnegie-Mellon University on a theory of human information processing in the context of theorem-proving skills in geometry.

The lack of funding for science education during 1982 and 1983 was the catalyst for an innovative effort on the part of science education program directors (who remained after the staff was cut to phase out existing grants and contracts) to find alternative means of supporting research in educational technology. They embarked on a pioneering program involving industry and universities when the National Science Board approved the use of computer equipment donated by industry as part of the National Science Foundation's resources. The program "Development in Science Education Involving NSF/Industry Cooperation for Science and Engineering Education Using Computers", supported projects developing creative, innovative prototypes of computer-based instructional materials or model programs that have strong potential for generating ideas for making significant improvements in the nation's science and engineering education efforts.[23] The projects were aimed at developing computer-based materials suitable for use in the 10th, 11th, and

12th grade and early college levels. NSF funding for these projects was $885,668. Computer equipment, valued at $947,217, was donated by industry for 51 of the projects. Grantee institutions, which had to provide at least a quarter of the project cost to receive an award, contributed at least $800,000. The program involved five of the leading computer corporations: Tandy, Atari, DEC, IBM, and the Apple Education Foundation.[24] The NSF subsequently broadened this program to include all science directorates.

The demise of the Science Education Directorate in 1982 created a hiatus from which the science education research and development community has taken several years to recover. Research groups were disbanded, some researchers moved to fields other than science education, some moved to military training research, and others went into private industry to do more applied work.

6. 1977-83: NSF Contributions and Impact

Ironically, NSF had no program focused on research in educational technology during this period of extreme activity and investment by schools. The lack of a focused program of research and development for innovations in technology during this period was partially compensated for by the large numbers and variety of technology-oriented proposals received by the Foundation in its other programs.

Although RISE funding was small, it was significant because it was the first time in NSF history that there was a program focused on research on learning and teaching. The work in cognitive science and artificial intelligence applications to instruction supported by the NSF during this period, although small in funding, was virtually the only research of this kind being supported in the U.S. outside of the military. (Previously, support for such work had been co-sponsored with the National Institute of Education). This was seminal work which, along with military research, now has a major impact on the field of intelligent CAI and intelligent tutoring systems.[25]

Some of the small DISE projects had major impact as models which were adopted by thousands of schools, picked up by software developers, and/or

emulated by educational publishers (e.g., Piestrup's Rocky's Boots; Hunter's My Students Use Computers; MECC's computer literacy studies; various science content videodiscs).

NSF's early support of interactive videodisc, going back to 1975, was the beginning of a major innovation which was later picked up by many other organizations, particularly military training.

The joint funding with NIE of research on cognitive processes led to important advances in the state-of-the-art in domain-specific studies in physics and closer relationships between cognitive science and technology.

Initiated in 1982, the joint program with industry is now a major force in computer-related innovation in education. Millions of dollars worth of equipment has been contributed annually by industry through this program.

7. 1984-87: The Context

By 1985, 80 percent of elementary schools and 95 percent of secondary schools had at least one computer for instructional purposes.[26] Having made a large and continuing investment in computing equipment, software and teacher training, U.S. elementary and secondary schools in the mid-1980s have been institutionalizing many aspects of the technology revolution. Roles have been established in most school districts and many schools for "computer coordinators". Large school districts have established their own computer maintenance shops. LEAs and SEAs have been establishing technology-related teacher training requirements and computer literacy course requirements. In many schools, the deeper and more difficult questions have begun to surface -- questions about the relationships between children and machines; about the cognitive, affective and social effects of the use of the technology with children; about the roles of teachers in high-technology classrooms; about curriculum implications of the information revolution and about the appropriate integration of technology into the curriculum and classroom.

8. 1984-87: NSF Funding

Since 1984, NSF has increased its R&D activity in technology through three programs which, to varying extents, support research and development in educational technology. The Applications of Advanced Technologies (AAT) program supports research and development on the application of advanced technologies, particularly computers and computer controlled technologies, to science and mathematics education. This program is concerned with issues at the forefront of technology applications to science and mathematics education. Funding levels for 1984, 1985, 1986 and 1987 were $1.2, $7.55, $4.74, and approximately $5 million, respectively. The Instructional Materials Development program supports the development of new or improved materials and strategies to support science, mathematics, and technology instruction in elementary and secondary schools. Funding levels for 1984, 1985, and 1986 were $14 million, $5.6 million, and $8.1 million, respectively. A little over half of the projects involve computers, calculators or video technologies in some way, but technology may be a minor focus of a given project. For rough estimation purposes, we are assuming 20 percent of these IMD funds to be directed towards development or evaluation of technology applications in elementary or secondary education. A third program, Research in Learning and Teaching, supports basic and applied research on the most significant factors that underlie effective teaching and learning. A small number of these projects involve research on technology-based systems for learning. About $0.5 million per year can be assigned to these projects.

Examples of work supported by AAT since 1984 include Anderson's development of geometry tutors for high school mathematics at Carnegie Mellon University; diSessa's work at the University of California Berkeley to create a new educational computing system called Boxer; Fey's work at University of Maryland on the effects of computer-based curricula in school algebra; Kulik's work at University of Michigan to synthesize research findings on key factors in science teaching and learning using instructional technology; several projects applying or extending LOGO in math; Resnick's work at LRDC at University of Pittsburgh on intelligent tutors for elementary and middle school mathematics.

9. Lessons Learned From NSF Experiences

It typically takes from eight to 12 years for a new technological innovation in education to mature. But NSF's SEE programs have typically lasted only two or three years because of the vagaries of funding support. Thus it has been only through dedicated efforts of a few program managers that key projects have had sustained support long enough to come to fruition. One way in which sustained funding for major work has been provided is through the informal collaboration among program managers across various research agencies in the government, both civilian and military. There are many examples of this collaboration such as most of the work in intelligent tutoring systems.

Until 1985, policies at NSF with regard to commercial rights and royalties on materials developed under NSF grants were such that they discouraged efforts at dissemination. These policies were changed in 1985 such that all income from the project after completion of the grant is assumed to go to the grantee institution. This should result in much greater incentives on the part of grantees to seek commercial publication of their work.

Another factor which in the past tended to mitigate against broad dissemination of results or products was the fact that nearly all grantee institutions were universities. This factor is now changing in that the NSF SEE is encouraging commercial publishers to become involved in the early stages of a materials development project.

The peer review system has in some ways served the purposes of educational technology well. It does, however, mitigate against highly innovative, multidisciplinary, complex projects which require long-range vision to support. For example, educational peer reviewers tend to support many aspects of the status quo within their disciplines or within school structures.

The organizational environment of the Science Education Directorate has not been totally suitable to highly innovative technology projects. For example, 12 years into the microcomputer revolution in the schools, the staff

at SED still has no computers of the type used in the schools, in order to demonstrate or review the software for which they are supporting development. On a more fundamental level there is a mismatch between the nature of technological innovation on the one hand and the structure of the program units on the other. Technological innovation, if it is to succeed in a school setting, involves all aspects of the overall educational system -- curriculum, materials, teachers, teacher training, equipment, testing and evaluation, publishers. The science education programs, on the other hand, are targeted in separate ways rather than towards total systems. There are teacher training programs but these are not coordinated with materials development, curriculum, or equipment or technology programs. There are graduate fellows programs which operate separately from the others and are unrelated to the substance of any technology innovation or curriculum reassessment.

Two recent study groups have recommended more strategic planning approaches to NSF science education.[27,28] An outcome of the 1986 study for the Applications of Advanced Technology Program was the determination that this program should address major and anticipated future problems in education, particularly in the area of preparing a pool of talented scientists and engineers, and it should do this through high-risk, potentially high-payoff, long-range projects that have the likelihood of making basic breakthroughs and orders of magnitude change in the quality of science education.[29,30]

D. DEPARTMENT OF DEFENSE

In terms of advancing the state-of-the-art, military R&D for educational technologies has generally led corresponding civilian R&D by several years.

The armed services spend far more on educational technology research and development than do all of the Federal civilian agencies combined even though there are far fewer military trainees than there are civilian students in elementary and secondary schools. At the same time, military R&D support for educational technology has represented only about one-half of one percent of the total military research, development, testing, and evaluation budget.

This section is organized into three subsections, describing military research and development in three major time frames: (1) 1960 to 1970; (2) 1971 to 1980; and (3) 1981 to the present. The fourth subsection provides a discussion of the available figures on amounts of funding by budget line items, how R&D are categorized in the military, and trends between 1975 and 1987.

1. 1960-70: Laying the Foundation

During the sixties, the military services laid the foundation for applications of technology to education/training by taking a leadership role in supporting research, development, demonstration, and evaluation. In this subsection, we summarize the roles of each of the services, the nature of the R&D projects and activities, and other contributions.

a. R&D Support by Service

(1) U. S. Air Force: 1955-70 Instructional Systems Approach. The Air Force has perhaps the richest history of contributions to computer-assisted instruction of all the services. As described later, this history can be traced back to the early fifties to the Air Force Personnel Training Research Center and related laboratories whose research scientists and staff included leaders (such as N. L. Gauge, R. M. Gagne, Robert Glaser, R. L. Thorndyke, Uri Brofenbrenner, and Norman Crowder, among others) in the programmed instruction and, subsequently, computer-assisted instruction movement. The Air Training Command was responsible for the world's largest and most complex training activity.

The first Air Force implementation of computers in training began in the late 1950s for on-the-job training of operators in the Semi-Automatic Ground Environment (SAGE) Air Defense System. According to Mayer,[31]

> "It served to demonstrate the tremendous potential of computers for equipment specific on the job computer-assisted training. It also demonstrated the feasibility of training subsystems build into operational systems".

With an emphasis on "embedded training", the Air Force research approach was to study: (a) how to adapt and modify programmed instruction and teaching machine technology to various types of performance training; and (b) how to adapt and modify operational systems to accommodate a supporting computer-assisted training capability.

As Fletcher noted, "SAGE set the stage for installation of computer-based stimulation and training in other Air Force command and control systems...".[32]

In the mid-1960s, the Air Force began to implement a number of projects based on "advanced instructional systems" research, including the Automated Information Retrieval Dial Access Learning Environment (AIRDALE) and subsequently the Diversified Optimized General Education System (DIOGENES). According to Fletcher[33], subsequently the Air Force contracted with Westinghouse Learning Corporation to prepare a feasibility study for the design of an advanced, multimedia instructional system to serve as a basic configuration for individualized instruction. These initial Air Force attempts contributed to subsequent developments during the 1970s and 1980s, such as computer-managed instruction and artificial intelligence.

(2) **U. S. Army: Mid-1960s-70s.** Department of Army support for education technology R&D received its initial impetus as a result of the McNamara DoD Directive which eventually led to the creation of a line item (6.3) for advanced development and training.[34] After high-level official correspondence based on various projections in 1966-67, the Army developed a position justifying computer-assisted instruction conceptually on the basis of a 20 percent savings in training time, the ability to individualize instruction, the ability to control and manage a variety of media, and other factors. After several feasibility studies and pilot tests during the late sixties, a major program using CAI was implemented in electronics training at the Signal School at Fort Monmouth. The initial results of this project were very positive, which resulted in the designation of a CAI task force group during the early seventies to investigate the application of CAI to numerous technical training areas.

(3) U. S. Navy: 1960-70. During the 1960s, the Department of Navy, particularly the Office of Naval Research under the leadership of Dr. Glenn Bryan, provided leadership among the services in developing the scientific foundations of computer-based education in training. Yet, as Fletcher noted, "Nonetheless, the Navy appears to be the last service to have begun applying computer-based instruction".[35]

Beginning in 1965, ONR, in its DoD-wide leadership role, sponsored three invitational conferences on CAI languages (at Stanford University, the University of Illinois, and Harvard University's Computation Laboratory), which resulted in general recognition that Joint Services cooperation would be required to make progress in the effort to develop a language which would approximate unconstrained natural language used in computer-assisted instruction. During the NSIA Conference (1966), Dr. Glenn Bryan was selected as the presenter for all three services on DoD's position on computer-based education in training.

ONR also sponsored an annual survey of the literature, conducted by ENTELEK, Inc., which included a state-of-the-art survey of centers for computer-based education activities and related information. During the decade, this annual survey was extremely influential within the R&D community.

The Navy initiated three R&D projects during the mid- to late sixties at the Naval Academy:

- the teletypewriter project which involved drill-and-practice and tutorial presentations that led students step-by-step through problems in eight courses;
- the IBM 1500 System, which provided instruction on four courses -- general chemistry, physics, Naval operations analysis, and basic Russian;
- a multimedia approach in three college-level courses including physics, economic analysis, and Naval leadership (funded by the Office of Education).

The Navy also conducted an extensive test of the IBM 1500 System in five configurations. This study was one of the first comparisons of program-control versus learner-control over student progress.

Unlike the Air Force which supported an instructional systems approach to educational training, of which CAI was only one of many components, the Navy's goal was to establish a computer-assisted support facility which could facilitate software development by the various commands, which would use the programs in educational training environments.

b. Elements of the Foundation for Future CAI

In this section, we summarize findings from an analysis of a representative sample of DoD-funded R&D projects during the early to mid-1960s, which focused on improving computer-assisted instruction in two respects: (1) to improve the educational function for which the computer is being used including simulation, problem solving, tutorial socratic, and testing; and (2) to improve functional elements of a CAI system which, if improved, would increase overall efficiency.

(1) Systems Configuration. Within DoD-supported projects, systems configuration was a top priority primarily: (a) because it was relatively inexpensive to adapt surplus equipment (e.g., from SAGE) used for information storage and retrieval to education technology; and (b) because of DoD emphasis on measuring efficiency and cost-effectiveness.

(2) Authoring Languages/Displays. A primary DoD focus was on developing authoring languages and displays associated with PLATO, several projects focused on plasma discharge technology in PLATO and various student response systems. Most projects attempted to improve terminal input/output by adapting existing equipment (e.g., light pointers, CRTs) for education and training settings.

(3) Machine Design. Very few DoD-funded projects focused on machine design and such related technologies as air cushion tape storage, tape quality, microtechnology, etc. One reason for this could have been domain

policies of the various agencies which discouraged publicly financed R&D in this area.

The average project size was approximately $30,000, with 85 percent of the projects having less than $200,000 per project year. Of the 34 projects in a representative sample, approximately 50 percent of the funds and 65 percent of the projects were available to approximately one-third of the sponsors. Of the 34 projects, nine were contracted with industry, 12 with universities, and the remaining to DoD in-house laboratories and agencies.

c. Other DoD Contributions: 1960-70

A number of specific contributions to computer-based education can be attributed directly to the DoD and individual services during the sixties.

(1) **Conferences.** The DoD undertook a major leadership role in sponsoring conferences and other information dissemination activities during this period. In addition to the ONR conferences noted above, the two prominent DoD-sponsored conferences were the NSIA Conference (Engineering Systems for Education and Training) in 1966, where DoD projected its needs for computer-based related technology programs to industry, and Project ARISTOTLE in 1967, when industry responded. Numerous workshops and symposia were also held by the services, particularly after the McNamara directive of 1965.

(2) **Civilian Spinoffs.** While the Department of Defense's formal position of using itself as a test bed for demonstrations of technology was clear, implementation varied considerably among the services. For example, the McNamara directive that services provide copies of nonclassified instructional material and media to requesting nonprofit educational agencies for the cost of reproduction and postage was not formalized with the Department of Education until the mid-seventies and implementation, once again, was minimal with the exception of initiatives taken by the Army at the Fort Monmouth Signal School. However, in spite of ineffective implementation, civilian spinoffs did occur in several areas (see case study below).

As noted above, DoD, through its official R&D funding and bootlegged O&M projects, laid a base for the development of a variety of components of a CAI system. Through joint services and other projects, funding levels were maintained or increased in important projects such as PLATO. Perhaps most important, the military services demonstrated new concepts in actual operational settings such as the "instructional systems approach", "embedded" training in SAGE, and cost-effectiveness models developed by the Army and Navy.

Perhaps the most important contribution of DoD during the sixties was the "transfer" of service and civilian personnel with expertise in program instruction, instructional systems, and computer-based education who, at varying points in time, left their services on assignment (e.g., to the Job Corps) or through cutbacks (e.g., Air Force Personnel Training Research Lab) to enter the civilian sector as consultants, hardware designers and vendors, and software developers.

2. 1970-80: Emergence of CMI and Simulation - Military

During the 1970s, funding support for R&D related to education technology increased steadily with an increasing focus on simulation and computer-managed instruction.

a. U. S. Army

The Department of Army sponsored R&D for a number of computer-managed instruction (CMI) projects. One of the largest was Project Impact, the design of a computer-based instructional management system over a six-year period (subsequently continued as Project ABACUS). By 1974, 15 Army projects were using CMI or computer-based simulation in training, including: the Quartermasters School, which developed simulations designed to provide accounting training; the Infantry School, which developed computer-based tutorial simulations in a variety of technical situations; and the Security Agency Training Center and School at Fort Devens, which developed a real-time CAI Morse Code Trainer, providing 260 hours of instruction for each student.

Another large Army-sponsored project was the Computerized Training System (CTS), which was similar to the large-scale Air Force AIS System, and involved the development of authoring languages. Significant R&D efforts focused on several components of the system, including the student mode, the instructional programmer mode, the instructor, and system programmer mode. During the mid-seventies, the Army significantly increased its funding support for human factors research, non-systems training devices, and simulation, as did the other services.

The Army attempted to pull together the state-of-the-art in a number of areas, beginning with computer-based instruction electronics training, which was completed in the early seventies, and computer-managed instruction, which included Project Impact and CTS. Building on the experience at Fort Monmouth with CAI, the Army contributed significantly to the state-of-the-art in conducting cost-effectiveness analyses of computer-based instruction.

b. U. S. Navy

While the Naval Academy Project continued with significant development in academy course work for such programs as chemistry, physics, Naval operations, and basic Russian, the focus of this project changed dramatically from CAI to computer "literacy". The Navy also implemented a large-scale demonstration program, known as the Computer-Managed Instructional Project at the Naval Air Station in Memphis, the largest computer-managed instructional effort in the world, with a daily student load of more than 6,700.

In late 1970s, Naval funding support increased dramatically for training in engineering technology, behavioral and social science, and human factors engineering development (including CMI R&D).

The Navy began to apply the results of many of its R&D efforts in operational settings, with varying degrees of success, implementing the largest computer-managed instructional project of its time in Memphis, increasing its R&D relating to simulators, and supporting much of the leading edge research relating to intelligent training systems, particularly through the Office of Naval Research.

c. U. S. Air Force

One of the major R&D efforts initiated in the sixties, which continued and extended during the seventies, was the Advanced Instructional System, the first major effort to apply computer-managed instruction on a large-scale basis in an operational setting. In addition to providing CAI and CMI support, the Air Force also launched major efforts to expand the use of flight simulation with the objective of reducing flying hours, fuel consumption, and operations and maintenance costs, and improving flight safety, training effectiveness, and combat readiness.

The Air Force, according to Fletcher, has "provided essential leadership at critical moments, and they have been significant for research and development in computer-based instruction".[36] The impact of "embedded training" in SAGE expanded in the Air Force throughout this decade. The Advanced Instructional System as a concept, and its specific emphasis on cost-effectiveness and management of multimedia instruction, had an impact beyond the Air Force, as reflected in redirected efforts toward computer-managed instruction in the other two military services.

During this time period, the three military services, in combination with DARPA, expanded their support for R&D on artificial intelligence and expert systems, providing a foundation from which many of the R&D centers and institutions which they supported could venture into industrial education and other training applications on an experimental basis. During this time period, DoD support for related technologies such as videodisc began to expand, building upon previous developments in the services and DARPA and heightening interest in potential civilian applications of these technologies.

3. Other DoD Projects: 1960-80

In this section we will describe some of the major centers of CAI, R&D, and/or projects funded by the Department of Defense during the 1960-80 period and their contributions.

a. University of Illinois: PLATO

The Coordinated Science Laboratory (CSI) at the University of Illinois received early support for PLATO (directed by Dr. Donald Bitzer) from the Joint Services Electronic Program and ARPA, the Army Signal Corps and Ordinance Corps, the Office of Naval Research, and the Air Force Office of Scientific Research. Virtually all of the initial funding for PLATO I and II could be traced to the above organizations. When PLATO III was developed, the Control Data Corporation began to make significant investments in that configuration. In 1966, the PLATO project was put under the Computer-Based Education Research Laboratory and a year later received a $475,000 grant from the National Science Foundation to set up demonstration centers in four schools. Military support was briefly cut off. After the first working plasma panel was produced, military support continued under an umbrella contract, through DARPA, which provided hardware and communications support for about 100 terminals at various military and civilian test sites. DARPA also awarded a contract to Education Testing Service to perform a separate evaluation of military use of PLATO.

Fletcher[37] reported that PLATO IV was found to be reliable and effective as an instructional delivery system for a wide variety of content areas and cost-effective for course material generation and validation. The system was not found to be cost-effective as an instructional delivery system. One of the most cost-effective applications was the use of interactive graphics and touch panel for instructional simulations. PLATO ultimately may not be as important in its own right as it is in the influence it exerted over computer-based instruction, especially where the following assumptions are made: (a) incorporation of graphics, especially interactive graphics, is not seen as a frill but as an integral and powerful component of instruction delivered by a computer; (b) sophisticated answer judging including spellcheckers, alternative forms of correct and incorrect answers, student evaluation, etc. are included in many systems as an essential component; (c) touch screen input is seen as important and desirable; and (d) computer-based instruction itself is seen as a major and desirable use of computers.[38]

b. Army 1500 System Evaluation Electronic Training

In 1966, a Second Lieutenant at CONARC developed a simulation model for assessing the cost-effectiveness of CAI and applied it to electronics training at the Army Signal Center School in Fort Monmouth, New Jersey. The simulation indicated that significant investment in CAI could be justified if trainee time could be reduced by approximately ten percent, taking into account the relatively high attrition rates (failure to re-enlist) of electronics technicians, the cost of training, and the opportunity costs of direct duty assignment to increase rate of return on investment.

A preliminary assessment was performed in 1967 with an eleven-hour block of instruction using the IBM 1500 System at the Naval Academy; this assessment indicated an average of eleven percent savings in training time and more positive attitudes. In June 1968, the IBM 1500 System was installed at the Army Signal School in Fort Monmouth, and self-phased course material was developed primarily in a tutorial mode. The materials were produced in-house by Signal School personnel, including the Lieutenant who had subsequently been reassigned to the Signal School. For three years, the first four weeks of instruction in Basic Electronics were presented and managed by the IBM 1500 System. A subsequent study found that students in the CAI program had higher mean scores, had 21 percent less attrition, and completed aptitude levels in 37 percent less time.[39] The Basic Electronics course materials eventually came to be used by 12 institutions of higher learning and a number of secondary schools, including Learning Technology Institute (Warrenton, Virginia), University of Alberta, National Technical Institute for the Deaf (Rochester, New York), and Montgomery County (Maryland) Public Schools.[40] This project also led to several technological advances, including a course writer interpreter, expanded macro systems for course writer authoring, and the first incorporation of computer authoring techniques to a general instructional model.[41]

c. Advanced Instructional Systems (AIS)

Following the successful use of computers in the SAGE systems for embedded, on-the-job training, in 1966, the Air Force designed several

projects to use computers to support one-way flow of audiovisual instruction through a dial-up, coaxial distribution system and, subsequently, to provide a central role in controlling instructional interaction and directing student progress. This resulted in an advanced development plan for computer-managed instructional systems, followed by a feasibility study for the design of an advanced multimedia instructional system which could be used as a basic system or for individualized instruction. In 1969, the multimedia instructional system was redesignated as AIS. In 1973, McDonnell Douglas was awarded a four and a half year, multimillion dollar contract to develop the AIS.

As Fletcher[42] notes, the AIS was used primarily for computer-managed, rather than direct, instruction. It also was one of the first projects to develop computational techniques and altered environments for computer-based instruction. The techniques on which the AIS language were based contributed to the development of ADA, the standard Department of Defense all-purpose language during the 1980s.

4. 1980 to Present: Intelligent CAI and Related Technologies

During this time period, all of the military services have continued or increased their R&D efforts in artificial intelligence and experimentation with emerging technologies such as videodisc, interactive learning, etc. Exhibit 3 lists some of the most important intelligent training systems supported by the military. Below we summarize some of the major R&D efforts among the three services, at a general level, and conclude with a listing of specific R&D projects related to computer-assisted instruction and cognitive learning which were undertaken during this time period (see Exhibit 4).

a. U. S. Army

The Army continued to focus on cost-effective education and training applications and evaluations. Through efforts of groups such as the Army Research Institute, the Army expanded R&D projects involving artificial intelligence and compensatory training and literacy skills. With other military services, the Army is developing: Portable Electronic Aid for Maintenance (PEAM); the Computerized, Hand-Held Instructional Prototype

Exhibit 3

INTELLIGENT TRAINING SYSTEMS IN THE MILITARY

System	Subject Matter	Sponsor	Knowledge Base	Student Model	Tutor	Reference
SOPHIE	Electronic Maintenance	Tri-Service (AFHRL[a] ARI[b], NPRDC[c]) and DARPA[d]	Semantic Network with Mathematical Model	Overlay onto Model	Simulation with Articulate Expert	Brown, Burton & DeKleer (1982)
STEAMER	Steamship Propulsion	Navy (NPRDC)	Mathematical Model Interfaced with Procedural Network	Overlay onto Model	Graphically Simulated Environment with advisor	Hollan, Hutchins, & Weitzman (1984)
IMTS	Corrective Maintenance of SH-3 Bladefold System	Navy (ONR[e] & NPRDC)	General Purpose Corrective Maintenance Network Network	Overlay onto Heirarchical Curriculum Concept Distance	Simulation with Human Instructor Interface and	Towne & Monro (1987)
CBMS	Memorization of Heirarchically Organized Concepts	Navy, Army (NPRDC & ARI)	Weighted Semantic Network	Overlay onto Network	Hints Linked to Problem Type	Halff (1986)
TRIO	Radar Intercept Officer Tactics	Navy (NTEC[f])	Rule-Based Representation with goal oriented problem solver	Overlay onto expert solutions	Real Time Simulation with Articulate Expert, Voice Interaction, and Demons	Feuerzeig, Ash, & Ricard (1984)
QUEST	Operation and Troubleshooting of Electric Circuits	Navy, Army (ORI & ARI)	Rule-Based, "Zero-Order" and "First-Order" Qualitative Models	Overlay onto Progressively Sophisticated Model	Simulation with Problem Generator and Explicit Queries	White & Frederiksen (1985)
SATS	Radar Signal Analysis	Air Force (AFIT[g])	Rule-Based Representation with Ordered Lists	Overlay onto Rule-Based Representation	Rule-Based Simulation and "Metatutor" with Problem Generator	Melvin (1986)
MACH-III	HAWK Missile Organizational Level Maintenance	Army (ARI)	Heirarchical Network	Overlay onto "Practical Doctrine"	Simulatior with Articulate Expert	Massey, Kerland, Tenney, Bruin, & Quayle (1986)
INCOFT	PATRIOT Missile Engagement	Army (ARI)	Rule-Based Representation	Overlay onto Expert Solution	Real Time Simulation with Articulate Expert	Feurzeig, Massey, Downes-Martin, & Ritter (1986)

[a] AFHRL - Air Force Human Resources Laboratory
[b] ARI - Army Research Institute for the Behavorial and Social Sciences
[c] NPRDC - Navy Personnel Research and Development Center
[d] DARPA - Defense Advance Research Projects Agency
[e] ONR - Office of Naval Research
[f] NTEC - Naval Training Equipment Center (now Naval Training Systems Center)
[g] AFIT - Air Force Institute of Technology

BEST AVAILABLE COPY

SOURCE: Dexter Fletcher, in press.

Exhibit 4

Summary Description of DoD R&D Projects: 1980 - Current

Cognitive Aspects of Flight Training
October 1976 - September 1989
Air Force Human Resources Laboratory
This long term research project aims to determine the thinking skills required by pilots and how these skills are developed, and which skills contribute to pilot success. The most recent aspects of this research include the use of microcomputers and eye tracking devices to determine the distribution of visual attention. It is hoped that this research will provide better methods for evaluating the potential of individuals to become skilled pilots.

Embedded Learning Strategies for Armor Officer Training (Advanced Development)
October 1985 -
Army Research Institute
This project attempts to apply knowledge on how people think to design better computer-assisted training courses. The computer-aided training developed under this project will record the students performance and allow for a printout of a representation of the students knowledge. An evaluation of the effectiveness of the training will be conducted. The prototype computer program undergoing pilot testing is to lead eventually to a system capable of capturing and displaying a student's knowledge of a subject area.

Semiautomatic Methods for Knowledge Enhancement
December 1983 - May 1986
Further Research on Semiautomatic Methods of Knowledge Enhancement
September 1986 - November 1987
Army Research Institute
This project is supporting the work at Edinburgh University and the Turing Institute on expert systems able to learn by induction, and to determine if the knowledge base can take its acquired knowledge to develop an understanding of a problem beyond the maximum ability of the expert. These areas will be tested using chess end-games. After acquiring knowledge of chess end-games, the computer system will generate a theory built from the behavior of the chess master's. The chess master will determine if by studying the theory developed that his understanding of end-games has been deepened. The procedures for applying these principals in other areas will also be tested.

Development of an Air Force Occupational Research Data Bank
May 1979 - September 1989
Air Force Human Resources Laboratory
This project is to design and establish a center to collect, analyze, and report on current airman and officer occupations. The consolidated data bank of Air Force job information that has resulted from this effort can be interfaced with statistical packages to perform longitudinal, cross-specialty, and cross-study analyses.

General Purpose Program Development and Maintenance

May 1979 - December 1999

Air Force Human Resources Laboratory

Provide development, maintenance, documentation, and training support for general purpose software related to AFHRL research programs. This includes providing systems analysis and programming support for existing software and the development of new computer programs.

Research Plan Workshop for Intelligent Tutoring System

February 1986 - January 1987

Air Force Human Resources Laboratory

This project was to organize and conduct a research planning forum and follow-up workshop on intelligent tutorial systems (ITS). Six white papers were to be commissioned exploring issues such as "What is the nature of instructional expertise and how can an ITS design capture such expertise?"

Knowledge Acquisition/Intelligent Authoring Aids

May 1985 - January 1989

Air Force Human Resources Laboratory

The purpose of this project is to develop software tools for use by authors with little experience regarding instructional design and computer programming. These tools will allow for the development of interactive computer-aided instructional (ICIA) student diagnostic modules (SDM) that will allow for training when human instructors in the area are unavailable. This project will validate this approach for implementing intelligent authoring aids.

Intelligent Computer Assisted Instruction Network Participation

May 1984 - January 1988

Air Force Human Resources Laboratory

This project supports the joint services ICIA network which is investigating intelligent computer-based training in order to expand and accelerate research, develop methods for adopting ICIA in the Air Force, and to facilitate cooperative research efforts in the area of computer-based training.

Semantics of Procedures: Smart Maintenance Trainer

November 1983 -

Army Research Institute

A project aimed at developing a system to teach diagnostic skills for complex items, such as electronic, mechanical, chemical, and electro-optic components. An automated authoring aid is being evaluated which provides the non-programming instructional designer with a powerful tool kit which can create and combine high resolution graphics, animation, interactive simulation, video, audio, text, quiz, questions, and students models for delivering instruction on standard army personal computers.

Job Skills Education Program: Curriculum Development

October 1982 -

Army Research Institute

By conducting detailed analyses of 94 military occupational specialties, a computer-based job-related curriculum will be developed. Existing curricula will be evaluated to determine its potential relevance, and an evaluation of of job/task analyses, course survival skills, clustering schema and curriculum models will be made. This will involved the revision of 420 hours of mostly computer-based curriculum for inclusion in the Job Skills Education Program. In addition, a comparison was made of computer-instructional systems including PLATO and Micro TICCIT.

Development of a Computer-based Map Interpretation and Terrain Analysis Course

March 1985 - September 1987

Army Research Institute

This project will include transferring images from 16mm film to videodisc and the development of software to provide a desk top computer-based navigational skills training package for army aviators. Both basic and

advanced levels of practice are to be available, both utilizing computer-generated graphic overlays to improve the visual presentation.

Smart Course Development

October 1983 -

Army Research Institute

Assistance will be provided in the development of the Engineer Officer Advanced Course, which includes providing advice on the management and implementation of computer-based instruction. A review of other army CAI and CBI efforts will be undertaken to determine their applicability to the EOAC, along with reviewing instructional psychology and cognitive research findings for application to this effort.

Intelligent Computer-Aided Instructions in Training Systems

October 1981 -

Army Research Institute

Research on the SMART (Skills Maintenance and Reacquisition Training) system is to be applied to training systems for complex weapons systems. This will include SMART training devices, artificial intelligence technology, portable computers, IDEAS (Intelligent Design Environment and Assistant System) and the portable computer tutor, CHIP.

ICAI Steamer

October 1986 -

Navy Personnel Research and Development Center

This project will evaluate the application of new artificial intelligence hardware and software in a Navy school setting. This work is part of the current work on advanced computer-based training on propulsion and problem solving, otherwise know as "Steamer", to determine what requirements exist to transition a relatively mature AI-based System to a fleet user; gather evaluation data on system use.

E-2C Operator System Training

October 1983 -

Naval Air Force (Pacific)

This project will determine the feasibility of inexpensive simulation technology used with either joint service or commercial authoring software to develop Navy training for a variety of objectives. Use available authoring software to develop computer-based instruction for Navy technical training; the target student is a replacement Navy flight officer for the E-2C aircraft.

Computer-Based Educational Software Systems

December 1982 -

Navy Personnel Research and Development Center

This project will adapt previously developed computer-based training programs for Navy implementation and for contribution to joint-service library of computer-based instruction. Develop quality standards for software and instructional adequacy of computer-based instruction; standardized machine-independent CBI programs; authoring support systems for CBI programs; specifications for required CBI hardware; demonstration system; user training.

Techniques for Diagnosing Errors on Problem Solving Tasks

August 1982 -

Office of Naval Research

This project will develop improved quantitative techniques for evaluating instructional materials and their sequencing; designing diagnostic tests; and interpreting how people perform on diagnostic tests. Use both theoretical and experimental approaches to refine a model diagnosing errors in procedural skills. This project will achieve improved understanding and use of diagnostic tests as a means of evaluating instructional materials and of discovering errors and misconceptions of trainees as they progress through a course of instruction.

S-3B Requirements Assessment

March 1986 -

Navy Personnel Research and Development Center

This project will determine the skills and knowledge needed to interpret computer-based imagery for the major sensor systems onboard the new S-3B aircraft. Analyze the cognitive requirements of each sensor system; analyze the skills and knowledge requirements for each sensor position; analyze impact of mission scenarios on cognitive requirements on the various crew members.

Computerized Testing Technology

October 1983 -

Navy Personnel Research and Development Center

This project will develop guidelines for the type of paragraph comprehension items that would improve the validity of future paragraph comprehension tests; determine whether ability to represent text or ability to decide among alternative answers is more important in test validity.

A Theory of Diagnostic Testing

April 1986 -

Office of Naval Research

This project will develop the foundations of the rule-space framework for diagnosing the misconceptions of trainees from their performance on cognitive tasks. Develop a mathematical/statistical theory for rule-space inferences.

Eighth Annual Meeting of Cognitive Science Society

April 1986 -

Office of Naval Research

This project is to support the annual meeting of the Cognitive Science Society, which will promote an interdisciplinary exchange of information in the areas of cognitive psychology, artificial intelligence, physiological psychology, psycholinguistics, and computer science. Organize workshops to bring together advocates of contrasting theoretical positions.

Comprehension Processes in Mechanical Reasoning

October 1981 -

Office of Naval Research

This project will achieve improvements in selection and training of Navy personnel for jobs which require mechanical and visualization skills depend on a thorough understanding of the cognitive components of these skills. Develop the needed detailed empirical analyses and computer simulation models of human visual and mechanical reasoning abilities; explain how people come to understand the workings of a mechanical device or machine by reading a technical text and inspecting a diagram.

(CHIP); and the Tri-Service Instructional Application Delivery System (TRIADS). Human factors research, during the early and mid-eighties, has focused on embedded training and has refocused recently on robotics and artificial intelligence as they relate to increased productivity. Simulation R&D also includes artificial intelligence, computer-assisted instruction, and robotics projects designed to accelerate learning, increase attention, and increase mental peak performance.

b. U. S. Navy

Many Navy R&D initiatives sought solutions to training problems through the introduction of individualized, automated, and simulation-based instruction and improved decision making about the use of computer-based training technology. In the human factors area, the Navy undertook numerous assessing methods of matching performance capabilities to systems requirements, adaptive interactive displays, expert systems, and computer-based aids for enhanced decision making, building on the initial base of the Steamer Project[43] and the application of state-of-the-art technology to repair, maintenance, and acquisition problems. Simulation R&D initiatives included development projects to: (1) facilitate transfer of knowledge from a subject matter expert to intelligence training systems; (2) design visual and sensor simulations for AI-based trainer designs; (3) upgrade or replace obsolete training simulators; and (4) identify alternative solutions with related training cost-effectiveness tradeoffs.

During the mid-eighties, the Training Performance Data Center (TPDC) (formerly the Training Data and Analysis Center (TDAC)) initiated an information collection effort and is compiling a catalogue of computer-based military instruction applications. This Center also assumed a major responsibility within the military services to assess the extent to which technology prototypes, which have demonstrated feasibility, are actually used.

c. U. S. Air Force

Influenced by the AIS concept during the eighties, the Air Force supported projects to develop instructional modules for identified job

prerequisites, specifications for evaluating training effectiveness, and initial specifications for advanced Training Decision Systems (TDS). The Air Force also validated the high school version of the Armed Services Vocational Aptitude Battery (ASVAB). Projects included empirical testing of a theory of visual discrimination and design efforts for multisensor, multicockpit combat mission training. Many studies focused on improvements and cost savings in training through simulation and computer technology. Air Force simulation R&D explored technologies such as computer image generation, holography, digital imaging, embedded training, and infrared systems. Other research efforts are designed to develop computer-based systems for authoring of training information presentation, drill and practice, testing, evaluation, and management. In FY 1987, approximately $95 million was allocated to the area of simulations and training devices R&D in the Air Force.

5. DoD Funding History for R&D Support of Technology: Summary and Analysis

The levels of R&D funding support for education technology in the categories education and training, human factors, manpower and personnel, and simulation and training devices within the Department of Defense during the 1970s and 1980s are depicted in Exhibit 5. With few exceptions, these data indicate that R&D support has increased during this time frame but has remained approximately one-half of one percent of the total RDT&E annual budget over the last two decades. The summary of this funding information is very brief, for a number of reasons:

(a) While the data indicate general trends, these funding levels are not as important as the specific types of projects funded by DoD during the last three decades and their contributions to the development and application of computer-based education and training.

(b) The official funding levels reported in annual budgets submitted to Congress and even in internal documents are somewhat misleading in several respects. The reported funding levels generally do not include education technology R&D support associated with large-scale weapons systems which could fall under Operations and Maintenance budget categories. Indeed, as noted earlier, some of the most risky and innovative R&D developments and innovations in DoD training technology were associated with these huge weapon systems development projects (e.g., SAGE, PIMO, etc.) because the failure could be more easily hidden in these types of initiatives than in personnel

training and research laboratories, etc. On the other hand, of those personnel training research categories, not all of the projects were technology based. For example, in the mid-1970s, due to frustrations in analyzing reported official funding levels, a team from DDR&E conducted field visits to sponsors' offices, labs, etc., to determine the proportion of R&D which was technology and non-technology based. As noted later, approximately two-thirds of the R&D was found to be technology based.

(c) During the last three decades, a number of the program elements (e.g. 6.1 - Basic Research, 6.2 - Exploratory Development and 6.3 - Advanced Development) and sub-elements underwent changes which created problems in assessing trends at the element and sub-element level within each of the military services. The time frame with the most accurate and reliable information is the period 1979 to the present, largely as the result of the Manpower and Training Research Information System (MATRIS). MATRIS was established in the late 1970s in response to OSD/DDR&E and Congressional questioning of the accuracy and reliability of the proposed service budget allocations and levels. Hence, most of the major attention below is directed towards recent years, describing the types of research and development projects and activities involved with various technologies.

Exhibit 5

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
6.1 Research	7.2	10.3	11.8	13.7	13.77	19.77	17.65	21.20	20.64	27.12	26.54	25.73
6.2 Exp. Dev.	28.8	37.7	47.5	57.6	54.65	69.14	62.16	72.12	80.64	83.48	89.60	96.97
6.3 Adv. Dev.	24.6	34.5	44.6	57.2	50.57	55.74	53.75	61.36	68.03	85.55	90.64	84.87
Total	60.6	82.5	103.9	128.5	118.99	144.65	133.56	154.68	169.31	196.15	206.78	207.57

Funding levels for the years 1980-1987 are supplied by the Manpower and Training Research Information System (MATRIS). The figures for 1976-1979 are from a different source. The differences between 1979-1980 may be due to some slight differences in the selection criteria and changes in program elements when MATRIS was established. The Congressional categories for education and training, human factors, manpower and personnel, and simulation and training devices are included. The above figures have not been adjusted for inflation.

a. Comparisons of DoD Funding: 1976-79 with 1985-89

(1) Fiscal Years 1976-79. During this time period, the goal of the Training and Personnel Technology program (Exhibit 6) was to achieve the best use of military resources. The objectives of the program were to maintain and

improve combat readiness; to reduce the costs of military weapons systems by reducing personnel and training costs; and to gather data to allow DoD management to make adequate analyses regarding personnel, training and staff-development systems. Major technology areas included: training devices and simulator development; training and education development to reduce costs and improve effectiveness; human factors in system development and operation. Exhibit 6 portrays funding by program element during this time period.

Exhibit 6

Training and Personnel Technology

Program Element	Title	($ in Millions) FY76	FY77	FY78	FY79
Army					
61102A	Training & Personnel	2.4	3.3	3.1	3.6
62716A	Human Factors in Military Systems	4.0	3.9	5.5	6.6
62717A	Army Personnel & Manpower Technology	2.3	2.4	4.1	4.5
62722A	Army Training Technology	3.1	3.9	5.0	4.8
62727A	Non-Systems Training Device Technology	0.0	2.5	2.3	4.3
63209A	Air Mobility Support				
D39	Flight Simulator Components	0.3	1.0	1.4	1.7
63731A	Military Personnel Performance Development	2.3	3.5	2.6	5.5
63738A	Non-Systems Training Devices Development	2.0	2.9	5.2	4.5
63743A	Training & Utilization in Military Systems	4.2	5.5	8.4	10.0
63744A	Army Contemporary Issues Development	0.5	0.5	0.5	0.5
		21.1	29.2	38.1	46.0
Navy					
61153N(42)	Behavioral & Social Sciences	3.3	4.1	5.5	6.4
62757N	Training & Human Engineering Technology	6.7	7.8	9.0	9.4
62763N	Naval Personnel Support Technology	1.7	2.6	2.9	3.0
63701N	Human Factors Engineering Development	1.6	2.1	3.5	3.7
63707N	Navy Manpower Control Systems Development	1.6	2.5	4.9	5.6
63720N	Education & Training	6.4	7.7	8.6	11.3
		21.3	26.8	34.4	39.4
Air Force					
61102F(2313)	Training & Personnel	1.5	2.9	3.2	3.7
62202F	Aerospace Biotechnology	4.9	5.7	7.1	7.2
62205F	Training & Simulation Technology	3.4	6.3	8.6	13.7
62703F	Personnel Utilization Technology	2.7	2.6	3.0	4.1
63227F	Advanced Simulator Development	0.3	3.0	4.9	9.5
63751F	Training & Education Innovations	5.4	6.0	4.6	4.9
		18.2	26.5	31.4	43.1
	TOTAL	**60.6**	**82.6**	**103.9**	**128.5**

As displayed in Exhibit 6, from FY76 to FY79 the Army increased basic research (6.1) funding from $2.4 million to $3.6 million. Spending for exploratory development (6.2) increased from $9.4 million to $20.2, with the Non-System Training Device Support program element showing the largest increase ($0.0/$4.3). Funding for all areas of advanced development (6.3), except one, more than doubled.

The Navy basic research program (6.1) increased from $3.3 million in FY76 to $6.4 million in FY79. Exploratory development (6.2) showed less of an increase than in the Army, going from $8.4 million to $12.4 during this time period. Advanced development (6.3) spending more than doubled in this period, from $9.6 to $20.6. The Human Factors Engineering Development ($1.6/$3.7) and Navy Manpower Control Systems Development ($1.6/$5.6) program elements had the greatest percentage increases.

During this period, the Air Force had the greatest percentage increase in training and personnel technology spending. Basic research (6.1) increased from $1.5 million in FY76 to $3.7 million in FY79. Likewise, exploratory development showed a large increase, from $10 million in FY76 to $25 million in FY79. The Training and Simulation Technology program element went from $3.4 million to $13.7 million during this period, showing the largest increase. The Advanced Simulator Development effort increased from $0.3 million to $9.5 million, while the Training and Education Innovations program element showed a decline from $5.4 million in FY76 to $4.9 million in FY79.

(2) **Fiscal Years 1985-89.** The goals of the Manpower, Personnel and Training R&D program (Exhibit 7) were to: (a) develop manpower models and tradeoffs; (b) study equal opportunity issues; (c) achieve unit productivity; (d) design for system readiness; (e) improve the sustainability of units and individuals; (f) design and analyze training systems; and (g) improve instruction strategies with critical technologies. Exhibit 7 shows funding by program element for this time period.

Exhibit 7

Manpower, Personnel and Training

Program Element	Title	($ in Millions) FY85	FY86	FY87	FY88
Army					
61102A	Defense Research Sciences	7.1	7.4	6.5	7.1
62716A	Human Factors Engineering Technology	11.0	12.3	17.4	15.4
62717A	Human Performance Effectiveness & Simulation	5.2	0.0	0.0	0.0
62722A	Manpower, Personnel & Training	6.8	0.0	0.0	0.0
62722A	Non-System Training Devices Technology	5.2	2.9	4.3	4.1
62785A	Manpower, Personnel, and Training Technology	0.0	11.8	15.3	15.6
63003A	Aviation Advanced Technology	0.0	12.0	10.8	6.8
63007A	Human Factors, Personnel & Training Adv. Tech.	11.4	36.6	27.2	38.2
63216A	Synthetic Flight Simulator Development	9.2	0.0	0.0	0.0
63731A	Manpower Personnel	11.4	0.1	0.1	0.0
63736A	Human Factors Engineering Applications	0.1	0.1	0.1	0.1
63738A	Non-System Training Devices Advanced Development	1.9	1.9	3.8	0.1
63739A	Human Factors in Training & Operational Effect.	9.7	0.0	0.0	0.0
63743A	Education & Training	10.1	0.0	0.0	0.0
63744A	Training Simulation	7.7	0.0	0.0	0.0
		96.1	84.5	84.6	86.8
Navy					
61153N	Defense Research Sciences, Sub-Element 42	12.5	12.1	11.71	10.3
62131M	Marine Corps Landing Force Technology	0.9	0.5	0.7	0.5
62233N	Personnel, Training & Simulation Technology	7.3	7.7	8.2	8.5
62234N	Human Factors Technology Area	3.3	4.1	3.6	3.8
62744N	Marine Corps Air-Ground Technology	0.0	0.0	0.0	0.0
62757N	Human Factors & Simulation Technology	0.0	0.0	0.0	0.0
62763N	Personnel & Training Technology	0.0	0.0	0.0	0.0
63701N	Human Factors Engineering Development	1.9	2.1	2.5	4.8
63707N	Manpower & Personnel Systems Development	2.7	3.3	2.9	4.1
63710N	Man-Machine Technology	0.0	0.0	0.0	0.0
63720N	Education & Training	3.5	3.0	4.8	7.7
63727N	Advanced Technology for Logistics Information	0.0	0.0	0.0	0.0
63732M	Advanced Manpower/Training Systems	2.9	2.2	1.8	3.3
63733N	Simulation & Training Devices	7.3	6.9	6.5	8.5
63739N	Navy Logistics Productivity	0.1	0.8	0.1	1.0
		41.7	41.9	42.1	51.9
Air Force					
61102F	Defense Research Sciences	6.2	6.7	7.6	8.6
62202F	Aerospace Biotechnology	10.7	10.6	15.3	15.5
62205F	Personnel, Training & Simulation	22.8	31.3	32.5	36.0
62703F	Personnel Utilization Technology	8.0	0.0	0.0	0.0
63106F	Logistics System Technology	0.0	6.5	10.8	12.8
63227F	Personnel, Training & Simulation Technology	7.0	8.1	7.5	11.0
63231F	Crew Systems & Personnel Protection Technology	4.0	4.4	6.8	7.6
63365F	Space Biotechnology	0.0	0.0	0.0	0.0
63704F	Manpower & Personnel Systems Technology	2.0	0.0	0.0	0.0
63751F	Training Systems Technology	5.3	0.1	0.1	0.3
		65.6	67.2	80.2	91.2
	TOTAL	**203.4**	**193.6**	**206.9**	**229.9**

Of the three service branches, the Army has shown the greatest decrease in spending for Manpower, Personnel, and Training during the last four fiscal years. Overall spending for Research (6.1), Exploratory Development (6.2), and Advanced Development (6.3) has declined from $96.1 million in FY85 to $86.8 million in FY88. Funding for some program elements has been phased out completely. The most dramatic decrease took place between FY85 and FY86. Research in FY88 continues at the FY85 level, while exploratory development shows a minor increase. The principal decline is in the area of advanced development, with virtually all program elements terminated except for Aviation Advanced Technology, and Human Factors, Personnel and Training Advanced Technology.

In the Navy, funding for research has declined from $12.5 million in FY85 to to $10.3 million in FY88. During the same period, funds for exploratory development program elements have risen slightly from $11.5 million to $12.3 million. However, all areas of advanced development have experienced an increase. Spending for Education and Training has more than doubled ($3.5/$7.7) along with funding for Human Factors Engineering Development ($1.9/$4.8) and Navy Logistics Productivity ($0.1/$1.0). Yet, total Navy R&D funding has remained much lower than funding levels for the Army and Air Force.

The Air Force had the sharpest increase in spending for Manpower, Personnel and Training from spending two-thirds of the amount that the Army spent to being the leader. The Air Force increased funding for research from $6.2 million to $8.6 million from FY85 to FY88. For exploratory research it has had large increases in the Aerospace Biotechnology ($10.7/$15.5) and Personnel, Training and Simulation ($22.8/$36.0) program elements, while eliminating funding for Personnel Utilization Technology. Spending on advanced development projects has increased from $18.5 million in FY85 to $31.7 million in FY88. The Logistics Systems Technology ($0.0/$12.8), Personnel, Training and Simulation Technology ($7.0/$11.0) and Crew Systems and Personnel Protection Technology ($4.0/$7.6) program elements have had the greatest increase. During this period, funding for the Manpower and Personnel Systems Technology and Training Systems Technology program elements has been virtually eliminated.

(3) **Implications.** Comparisons between the two periods point to several important trends and implications.

First, during the late 1970s, all services experiences consistent increases across all R&D line items; during the 1980s, the Army experienced a drastic decline, the Air Force experienced almost a 50 percent increase, and the Navy funding level has remained essentially constant. The recent lack of funding consistency and continuity undoubtedly has had considerable impact on R&D activities, particularly in the Army.

Second, in the eighties, both the Army and Navy experienced declines in funding support specifically for research (i.e., 6.1), while Air Force expenditures increased only marginally. These trends within the services and similar trends in DARPA indicate that a relatively low priority is being placed on basic research; this has implications for knowledge-base building and continued support for the entire research community. Indeed, a number of key professionals in the field have recently left civilian research positions. Because DoD support increasingly focuses solely on military applications, the opportunities for civilian spin-off appear to be shrinking.

And last, the amount of DoD educational R&D funding is considerably higher than that provided by all other civilian agencies. This factor suggests that there exists a number of opportunities to facilitate technology transfer from DoD to civilian counterparts. However, this continues, as it has for three decades, to be a missed opportunity.

III. ILLUSTRATIVE R&D PROGRAMS

In this section, we describe briefly seven successful programs which relate to education technology research, development, demonstration, implementation, and innovation. These examples were selected to illustrate important characteristics of the field of educational technology R&D such as links between Federal research and the commercial sector, organizational climate within agencies, and duration of research programs. We have distilled salient features, characteristics, and factors contributing to their success in order to provide a basis for a discussion of factors that, in general, influence successful R&D programs (in the next section). These successful programs -- not necessarily in the order of their importance -- are:

- The Instructional Systems Approach (ISA) and Computer-Based Education in the Air Force: 1950-61. The Air Force's ISA experience not only made an important contribution to the educational technology field generally, but also identified important factors affecting the way R&D projects lead to innovative activity and use.

- Rocky's Boots and The Learning Company. The evolution of Rocky's Boots and The Learning Company from initial research and development through commercialization illustrates the potential contributions of Federal R&D support, as well as some of the problems inherent in commercializing a product.

- Office of Economic Opportunity. Although the potential for demonstrating new technology was never realized during OEO's seven years of existence, its organizational climate and flexibility provided unique incentives and opportunities for the private sector. Its lack of authority and political tenuousness contributed to the demise of one of its major R&D programs, but the other (Job Corps) continues today, making significant contributions.

- DARPA. Unique as a Federal R&D support agency, DARPA's success in contributing to basic research and development relating to artificial intelligence, video, interactive video, human factors, and related areas can be attributed to its clearly specified mission -- strategic placement of funding, maximum flexibility, and unique project management practices -- all of which contributed to its many successful efforts during the last three decades.

- Education Department/Office of Special Education Programs. This successful program, spearheaded by the Media Services/Technology Program, not only supported technology development, but also provided multifaceted support to create a market for special education

technology, relying upon incentives to make the market mechanism work more efficiently in a traditionally "thin market".

- LOGO. The development and commercialization of LOGO extended for well over a decade and a half, involving numerous Federal contributions to various developers and investigators. Not only is the LOGO story an example of high risk/high payoff R&D, but it also highlights some of the problems associated with Federal R&D support of ideas that do not fit a traditional mold.

- Technology Transfer from DoD to Civilian Education Applications. The observations of participants and others associated with various attempts to encourage technology transfer of defense education products into the civilian sector are briefly discussed. While formal structures to facilitate DoD spinoffs have not been successful, indirect spinoffs through knowledge and people have occurred through an informal -- and sometimes serendipitous -- process.

A. INSTRUCTIONAL SYSTEMS APPROACH (ISA) COMPUTER-BASED EDUCATION IN THE AIR FORCE: 1950-1961

Most knowledgeable experts agree that Department of the Air Force research and development activities during the 1950s contributed enormously to the application of programmed instruction, instructional systems approach (ISA), and computer-based education during the next two decades. The evolution of ISA is not only important as a success story but also suggests some of the ingredients necessary for successful R&D support for education technology. It also provides insight into the problems of transferring research into application, the various roles that industry can play, funding and other institutional arrangements, and the critical need for leadership in undertaking risky R&D activities.

1. Chronology of Major Events, Activities, and Impact

Exhibit 8 displays the time line of major events culminating in the SAGE system and the 1961 Policy Letter which led to the system-wide application of programmed instruction and the ISA within the Air Force. This letter was cited in the rationale for Secretary McNamara's 1965 directive creating the line item for advanced development in education and training. The time period might be classified into two phases: (1) 1950-56, in which research on programmed learning occurred largely at the Air Force Personnel

and Training Research Center (AFPTRC); and (2) 1957-61, in which laboratory R&D efforts were put under the Air Force Systems Command (AFSC). The former concentrated on the feasibility of auto-instructional devices; the latter on the potential for on-the-job training using the the instructional system approach. Several findings are noteworthy.

Exhibit 8

Evolution of Instructional Systems Approach/
Technology Research and Development
in Air Force: 1950 - 1961

Date	Major Event	Activity/Impact
1. 1954 Air Force Training Aid Research Lab	A "Principles of Radio" entire course using only recordings. B-47 technicians training by recorded lecture with film. English language instruction for allied pilots by tape and film.	Ability to demonstrate the the feasibility of applying automation to instruction. Also showed an economic advantage for training small, scattered groups of techni-technicians.
2. 1955 Air Force Personnel Training Research Center (AFPTRC)	MIPS developed with Hughes Aircraft as a training aid in presentation of information and testing.	Advanced instrinsic or branching programming and served as a prototype for the commercial Auto Tutor Teaching Machine.
3. 1955 AFPTRC	SMT developed by contract with Hughes Aircraft for armament systems mechanics.	Provided self-instructional opportunities for operational personnel.
4. 1955	"Handy-Dandy" by contract to S.A. Maurer, Inc.; second volume by Polan Industries in 1955.	Stop-frame feature of the "Handy-Dandy"/8mm cartridge, which can be used in a variety of educational and training situations.

5. 1956	AFPTRC phase-out through 1957.	Personnel at the center scattered to other assignments in the Air Force, industry, and university teaching and research.
6. 1958	Conference "Art & Science of Automated Teaching of Verbal and Symbolic Skills".	Generated renewed Air Force interest in the field of programmed learning; also stimulated interest in other sectors. Conference proceedings frequently cited; led to initiate Project 9778 ($5.2 million between 1958 and 1964)
7. 1958	"Communications Electronics Principles" with contract U. S. Industries, Inc. at Keesler AFB.	Study added to the small body of knowledge presently existing on comparative cost analyses of training methods.
8. 1958	Experimental Bomb-War System Mnt. Trng. Contract with Lockheed Electronics Company.	Emphasized "tradeoffs" between personnel training and new weapons hardware systems.
9. 1959 Decision Sciences Lab	Investigation of auto-instructional devices; contracted with AIR, MIT, and Harvard. Concluded that SMT and Navy Autorater could be applied to SAGE.	Simulated research in automating the entire learning task of the SAGE system, which included both background and operational training. Although it was demonstrated that instruction under the automated system was effective, a problem emerged in keeping the programs and machines updated to match the changing technology of the SAGE system. This program generated a research effort to design into otherwise conventional equipment capacity to automatically train its own operators (i.e., embedded training).
10. 1961	Policy letter by Headquarters DAF, October 30, 1961.	Policy letter represented a major transition in the programmed learning movement from emphasis on laboratory experimentation to equal emphasis on applied research. Cited in justification for 6.3 advanced development line item for McNamara memo.

First, the events and activities which had the greatest impact were those in which a technique was demonstrated in a natural setting rather than in a laboratory. And, in seven of the nine major events, "test bed" areas for demonstration were in the maintenance and operation of new equipment ranging from the B-47 to SAGE. At least 62 studies on programmed learning emanated from Air Force labs, constituting about one-fourth of all the research activity in this field in the United States. These findings lend support to the contentions of knowledgeable individuals that: (a) demonstrations are more effective than studies in leading to follow-on activity; (b) demonstrations are more effective if conducted in actual training situations rather than labs; (c) financial support for demonstrations appears to be more easily gathered when the training techniques are associated with new equipment or weapons systems training than in formal, technical school instruction; and (d) a large portion of the significant "developmental-through-prototype" funding comes from operations and maintenance budget categories.

Second, most of the contracts (i.e., eight of ten) were let with industrial firms, for several reasons: (a) industry could provide an unofficial means for the laboratory people to communicate with high-level commands when it was difficult for laboratory officials to do so directly; (b) industry had a greater incentive to promote the adoption of a new technology than did lab personnel (in fact, often there is a greater incentive among lab directors to raise more questions than provide answers in order to get dollars for next year's funding); and (c) the rate of turnover of military and civilian personnel in training research labs was high, often resulting in incomplete studies or the failure to initiate long-run studies. The impact of "contractual support" led to the shift in emphasis from laboratory studies to applied research under practical training conditions.

For example, Parsons, Inc. and Serendipities Associates not only conducted parallel efforts during the feasibility phases of PIMO (Presentation of Information for Maintenance and Operations), but also worked very closely with and supported the Air Force staff. Some argued that industry provided more than solely a contractor role in the diffusion of innovation. Where the "problem" was the stimulus, in-house labs sought the solutions, attempting to determine the best of existing techniques or to develop "specs" for a new one.

More often than not when hardware was involved, they contracted with industry. When the technology is the stimulant, industry took the initiative as "problem monger" (i.e., to find a problem for their technology to solve), which might have been one of the reasons for diffusion of the technology.

Third, the nature of inventive activity within the Air Force laboratories was largely concerned with studies on programmed learning without any real emphasis to apply the results. Potential for application began to be emphasized after the previous laboratory activity was put under AFSC. The first serious studies on the cost-effectiveness of programmed learning techniques were initiated in the early sixties. Even if the AFPTRC had continued, many doubted that it would have (even if it could have) experimented with programmed learning in real, large-scale, practical training situations.

Fourth, the phasing out of the AFPTRC in 1956-57, aside from its being put under AFSC, affected the nature of inventive activity elsewhere. Many researchers left the Center to go into industry, centers of programmed learning activity in universities, other Air Force research laboratories, and operational training commands. There are indications that this "invasion" actually promoted innovation by: (a) increasing the personnel communication opportunity between researchers and operational offices; (b) freeing those researchers who wanted to follow their idea through to fruition and practical application (which was not the mission of the AFPTRC); (c) getting industry involved in the education technology market and providing the basis for such devices as 8mm film cartridge "stop frames", the Auto-Tutor, and others; and (d) creating centers of programmed learning (e.g., American Institute for Research) within and/or attached to universities which have been the major contractors for the Air Force in non-weapons R&D training programs.

In summary, significant inventive activity in the Air Force, leading to the Policy Letter of October 1961 and the application of ISA, got to the demonstration stages, used industry contractual and other support, was directed to and funded under O&M, and was the result of a diffusion of individuals who, through personal contact, stimulated activity in industry, at universities, and in Air Force operations.

2. Findings and Their Relationship to Project HINDSIGHT

The above findings are very interesting when contrasted with those of Project HINDSIGHT, a two-year study on the characteristics of innovation and inventive activity in the weapons area.

a. Time Lag

One of the findings in HINDSIGHT was that, for half of the major events (excluding the innovative idea forming the kernel of the event), the scientific and technological base had existed for over five years prior to the initiation. The underlying scientific base was concerned with programmed learning, which was formalized during the early fifties, although stimulus-response research had begun several decades earlier. The feasibility of automated individualized instruction in training was shown as early as 1954 in the Air Force, but emphasis on organized implementation did not occur until 1962.

b. Communication

In over half of the major events in HINDSIGHT, communication of research results were informal, largely on a "person-to-person" basis. Documents, papers etc. were not important in stimulating new ideas; rather, they were used as support for arguments, back-ups, and references. Although this question, per se, was not raised during HINDSIGHT, several inferences tend to support this conclusion. First, demonstrations of the effectiveness of new techniques tested in natural training settings and usually tied to priority "test-beds" had a much more significant impact than studies on the feasibilities of new techniques. Second, personal and informal communication through "invasion" by individuals appears to have been more effective than documents. The closing down of the AFPTRC and release of personnel certainly contributed to this means of promoting innovation. Also, through the centers, etc. which were established by former AFPTRC personnel, demonstrations of new techniques were as effective as those carried out in Air Force programs. Third, industrial involvement in those major developmental tasks indicates

that it too provides unofficial communication links between laboratory and operations staff and among various operations groups.

c. Funding

HINDSIGHT found that in 43 of the 63 major events, the funds which launched the event were discretionary rather than expenditures which had been allocated for that particular development. The ISA evolution certainly was in line with this finding. It also explained why strong leadership and perseverance are critical; for once the initiative is taken, the initiator has to do his best to ensure that his career is not jeopardized by a failure.

d. Environment

In 62 of the 63 events studied in HINDSIGHT, an adoptive (i.e., authority based on task at hand and not on position in hierarchy) rather than authoritarian environment existed. Moreover, the environment had to be permissive for the initiator to move with the idea from conception to application at the location where the idea originated. This occurred in 55 of the 63 events. Sub-project officers in the Air Force followed each task from beginning to end. Professionals (i.e., educators, programmers, etc.) were the task masters and had freedom within parameters, once the project was designed and initiated. Strong leadership was essential in meeting deadlines.

B. ROCKY'S BOOTS AND THE LEARNING COMPANY

The Learning Company (TLC) is an eight-year-old firm based in Menlo Park, California, which develops and markets educational software for home and school use. TLC software is sold throughout the United States, with sales amounting to about $3 million dollars in 1986. TLC's products have won numerous awards, and the company has been widely regarded as one of the key innovators extending the state-of-the-art of educational software for personal computers.

A Federal grant in 1980 played an important role in creation of the company and in development of one of its most widely praised products,

"Rocky's Boots". For this reason, TLC's history may contain lessons for those interested in Federal policy.

1. Origin and Creation of Advanced Learning Technology, Inc.

The origins of TLC begin with Ann Piestrup, its founder. Dr. Piestrup began her career as a teacher, and later entered a doctoral program in Educational Psychology at U.C. Berkeley. During and after her doctoral work, she worked for a research firm studying successful reading and math programs and products for poverty area children. It was her observation that successful programs and products were very difficult to transport from one classroom or school to another, largely due to variations in teachers' attitudes.

Stimulated by a friend, she began to think about using personal computers for education. This was in 1978, when very few personal computers could be found in schools or homes, and their use was more difficult due to the lack of programmer's tools. However, the Apple Education Foundation had recently been created and intended to give some computers away for educational uses.

Dr. Piestrup knew little or nothing about computers, but persisted in discussing her ideas. Carolyn Stauffer, who worked at the Apple Education Foundation, discouraged Piestrup from pursuing an idea for a reading program, because she had had extensive discussions with teachers about what they wanted. She suggested that, instead, a program be created for preschoolers using spatial concepts. After locating a programmer, and purchasing letterhead for her fledgling Advanced Learning Technology company, Piestrup received an Apple Education Foundation grant (an Apple II and $1,000), and began work on a program to teach concepts of up/down and left/right that later became TLC's "Juggle's Rainbow".

2. Award of the NSF-NIE Grant Leads to Commercial Success

Knowing that the Apple money was not sufficient to pay her programmer -- let alone others -- Dr. Piestrup decided to apply for a grant from the U. S.

Department of Education (ED). She proposed to develop software to accompany new episodes of the ED-funded television program "Villa Alegre". The application was submitted and the funds were "committed" by ED for this project, but then a key Assistant Secretary left and the project fell through.

Next, Piestrup and two colleagues learned about the NSF-NIE competition for projects to improve "Pre-College Mathematics Education Using Computers", jointly funded and managed by the NSF and the National Institute of Education, with NSF acting as the lead agency. Dr. Piestrup's group prepared an application in time for the deadline, which was three days away.

While they waited months to hear about funding, both of Dr. Piestrup's colleagues went on to other endeavors. Thus, when preliminary indications on the grant were positive, she had neither a programmer nor a math education expert, both of which were necessary prerequisites to the grant award. Through her contacts in the software community and at Apple, she located Warren Robinett, who had written software for the Atari 2600 game machine, and Teri Perl, who had developed commercial materials for education and had earned her Ph.D. in mathematics education at Stanford University. (Piestrup recalls that NSF also insisted that a mathematician be available as a consultant. With the entire grant hanging in the balance, Piestrup did not argue, but felt this was unnecessary.) Still without complete assurance that the NSF-NIE grant would be awarded (the negotiation phase took months), Dr. Piestrup decided to incorporate the company upon award of the grant and become Advanced Learning Technology, Inc. (ALT).

The NSF-NIE grant (NSF #SED 80-12510) was awarded in September 1980 -- one of about nine chosen from a field of over 180. The budget period was 17 months, until February 1982, and the amount was $130,000. Dr. Perl had also won another ED grant (a Women's Educational Equity grant on women and mathematics), and so spent only 80 percent of her time on the NSF-NIE grant.

Mr. Robinett had developed a room-and-object drawing program that was known as "The Utility", to speed up the development process. The first programs developed later became TLC's "Gertrude's Puzzles", in which shapes are sorted according to certain attribute rules. Next, development began on

what was to become "Rocky's Boots", in which logic gates can be assembled to build a variety of different machines.

These programs, in the rough form that existed, were delivered on a disc to the National Institute of Education and to the National Science Foundation. Additional disc copies were made available to the public at cost. However, the programs in that form were not considered publishable by the authors; all of the great variety of detail necessary for commercialization (polished concepts, smooth operation, proper use of sound, color, and timing, title pages, on-screen instructions, packaging, etc.) was not yet in place. Dr. Perl has presented illustrated talks about software development which make this very point, using the early programs, compared to later commercial versions, as examples. Thus, when Rocky's Boots was published it was a proprietary derivation from Logic Tools, which was the predecessor program delivered to the government and placed in the public domain. Logic Tools had only a few kinds of logic parts, and no text. The program worked relatively poorly, and needed substantial redesign.

During the period of the NSF-NIE grant, the three founders of Advanced Learning Technology, Inc. were joined by Leslie Grimm, a teacher aide for learning-disabled children who taught herself to program and was experimenting with educational games of her own design. (She had previously earned a doctorate in biology at Stanford.) Two of these, "Magic Spells" and "Moptown", were licensed to Apple, with the royalties to be split between Grimm and ALT.

It became clear to these four, and particularly to Piestrup, that further progress (at least on the scale which they hoped for) would require a substantial infusion of money. Despite some misgivings, they each became stock owners, and made arrangements to seek venture capital. As it happened, however, a venture capitalist found them first and began negotiations. While these were under way, ALT acquired a President, Jack Smyth, and a business plan. Then, in January 1982 a major portion of the company's stock was sold to Melchor Venture Management, Inc. Shortly afterwards, on the advice of a Los Angeles advertising agency, Advanced Learning Technology became The Learning Company.

In 1982 TLC prepared six products for market. According to Grimm, Rocky's Boots (which began under the NSF-NIE grant) was the showpiece of the company, gaining it wide recognition. (The other five products were: Juggle's Rainbow, Gertrude's Puzzles and a simpler version, Gertrude's Secrets, Bumble Games, and Bumble Plot.)

Unfortunately, recognition was not enough. The company had made poor pricing decisions and was foundering. A series of major changes took place, including bringing Marcia Klein in (from the Regis McKenna advertising agency) to replace Jack Smyth as President, other personnel changes (including the departure of Warren Robinett), an office move, a new company logo, etc. In January 1984, The Learning Company was able to present a new image, new pricing policies, and many new products at the Consumer Electronics Show. Several important distributors began to carry TLC products, and the company was on the road to good health.

One later personnel change is noteworthy: in 1985, Ann Piestrup was forced to leave the company. She has since rejoined it on a consulting basis.

3. Lessons Learned

a. Royalty and Copyright Policy

In a sense it was fortunate for the development team that the software development process is so lengthy and painstaking. If the programs prepared under the NSF-NIE grant had been complete and final, the developers would have been faced with a dilemma, because at that time generally only $10,000 of royalties or receipts could be kept on each program that had been developed with NSF funds, with the remainder to be returned to the Treasury (although the policy could be negotiated on a case by case basis).

Subsequently, NSF (and ED) policies on program-related income were changed. Now, for example, the Assistant Director for Science and Engineering Education is inviting textbook publishers to help develop innovative science teaching materials, with matching funds from the NSF, and share in the

royalties. (A similar situation holds for computer software.) The new NSF policies were adopted specifically to increase incentives for developers to market their products. (NSF policies here refer to the policies of the Directorate for Science and Engineering Education; other Directorates may have different policies.) ED policy is evidently that if project-related income is put back into similar or related efforts (e.g., development of additional materials), then the recipients can keep the money; otherwise, the funds revert to the Treasury. (This policy originated with ED-funded television series, such as Sesame Street.)

Policies to cover the grant to ALT were pieced together to handle the situation and protect rights of both the grantee and the public. The computer programs developed were placed on discs and made available at cost ($10 or $20). A total of something like 150 of these discs were sold. In addition, paper listings of the code for the programs were submitted to ERIC and made publicly available. Subsequently, both IBM and Simon and Schuster requested this code from the government, possibly hoping that the public domain programs could be distributed with little or no modification; both also negotiated with TLC directly. (As indicated above, substantial further work was needed to turn the public domain programs into commercially successful products.) Principals in ALT were careful to document thoroughly what was developed when and by whom (including material developed before the grant was awarded), so that rights and ownership could more easily be determined.

b. High Payoff

About 15 awards totaling $1.5 million were made under the NSF-NIE competition, which was held in fiscal years 1980 and 1981. The grant to ALT was for $130,000. Assuming that Gertrude's Puzzles and Rocky's Boots would not have been developed were it not for the grant, the public has been willing to spend millions of dollars for educational programs which required $130,000 of the taxpayer's seed capital. If we further assume that The Learning Company would not otherwise exist were it not for the grant, then the taxpayer's investment resulted in creation of a company which became a leader in educational software. In either case, the indirect effects are also large: other individuals and companies were strongly influenced by the nature of The

Learning Company's software. While all of this might have occurred without Federal investment, in the case of Ann Piestrup it probably would not have -- she might well have given up. Others might have done something similar, but it is unlikely that it would have happened as soon. Ann Piestrup points to the freedom available under a Federal grant as a great advantage, compared to private funding. The strict market orientation of private funding, in her experience (or, "what will sell in Toys 'R' Us"), can and often does inhibit creativity.

c. Interagency Cooperation

This is one of those pleasant examples showing not only that interagency cooperation can take place, but that it can work well. "Champions" in each agency helped make the competition a reality, although funding cutbacks in fiscal 1981 (under a new administration) reduced the amount of the funds available. Both agencies had strengths to contribute (e.g., NSF had done a lot of development work with new technologies, while NIE had extensive experience with mathematics education research). Despite the interagency flavor (e.g., reviewers from both agencies), many people remember the grant as "an NSF grant", probably as a consequence of the fact that NSF was the lead agency, and also monitored the award.

C. OFFICE OF ECONOMIC OPPORTUNITY: CONTRIBUTIONS BUT MISSED OPPORTUNITIES

The Office of Economic Opportunity was created by Public Law 88-452, known as the "Economic Opportunity Act of 1964". Two programs supported R&D for education technology directly or indirectly: (1) Title I, Part A -- the Job Corps; and (2) Title I, General Community Action Program Section 207 -- Research, Training, and Demonstrations. Both of these programs had a significant impact on education technology -- including computer-assisted instruction -- during the 1960s and, through the Job Corps, well into the next two decades.

1. Job Corps

Although the Job Corps was an operational program, it also encompassed a number of R&D activities. Part of this diversity can be attributed to: (a) the flexibility of the legislation; (b) the influence of the private sector -- particularly defense-oriented companies -- which supported the use of the "systems approach"; and (c) the activities of R&D staff from the Department of Defense who were assigned to Job Corps planning, development, and evaluation activities.

One of the most influential members of the task force that created OEO and Job Corps was Dr. John Rubel, Vice President of Litton Industries, who advocated the applications of the "systems approach" in Job Corps and felt that the use of technology would be an important by-product of this application. Rubel and other members of the task force felt that the Job Corps would provide a unique opportunity to demonstrate the effectiveness of technology in education training and thereby "create a marketplace for such services to be bought and sold".[44] Even though developmental funds were minimal, the use of cost-plus-fixed-fee (CPFF) contracts allowed for significant development opportunities on the part of the private contractors -- either firms or universities -- that operated Job Corps Centers.

The Job Corps program made several significant contributions to the computer-based instructional movement:

- Personnel, particularly from the Air Force Training Command, who were assigned to or became employees of the Job Corps had opportunities to apply their programmed instruction and education technology expertise developed in the military. Indeed, many of the staff at the Air Force Personnel Research Training Center, closed during the mid-fifties, worked on Job Corps programs.

- Job Corps staff and contractors developed a number of instructional packages designed to help Job Corps participants pass the GED exams and to incorporate basic education into skills development programs (e.g., basic math taught as part of a chef's training program). One of the significant packages developed during the sixties in the Job Corps was the Sullivan Series to teach basic skills. This series was adapted and used by other publishers in OEO's Performance Remedial Incentive in Education Experiment, in which private firms were paid on the basis of student performance. Many variations of the Sullivan Series were reformatted for use on microcomputers and videodiscs during the late 1970s and early 1980s.

- The Job Corps offered opportunities for contractors to field-test, in a structured environment, many of the education programs which they had developed and would subsequently convert to computer formats. Firms operating Job Corps Centers included Sciehce Research Associates (IBM), Litton Industries, and U. S. Industries (then headed by Norm Crowder, formerly of the Air Force Personnel Research Training Command Center), among others.

2. Community Action Programs (CAP) Research, Training, and Demonstrations

The Director of OEO was,

> "authorized to conduct, or to make grants or to enter into contracts with institutions of higher education or other appropriate public agencies or private organizations for the conduct of, research, training, and demonstrations pertaining to the purposes of this part. Expenditures under this section in any fiscal year shall not exceed 15 per centum of the sums appropriated or allocated for such year to carry out the purposes of this part".[45]

While not specifically authorized, an education technology unit was created within Research, Training, and Demonstrations for a number of reasons:

- Many of the Department of Defense personnel involved in the creation of OEO were the proponents of education technology and had strong expertise in the field.

- Many firms entering the education market, particularly defense contractors, not only supported the unit's creation but were instrumental in its design. Indeed, many viewed the education technology unit as an alternative to the U. S. Office of Education (USOE) as a funding source for R&D, because USOE at that time could not contract with profit-making firms.

- Many proponents of education technology, both within OEO and in industry, felt that unique opportunities were available to demonstrate the effectiveness of technology in OEO-sponsored programs because virtually all such programs were outside the traditional school environment[46]

- Because both CAP and the Job Corps used Armed Services Procurement Regulations, many firms supported development activities under CPFF contracts and retained rights to resulting products without being subject to "public domain" policies associated with general Federal R&D support for technology.

- Several high-level USOE officials supported the creation of the OEO education technology unit because such a unit could identify

opportunities for R&D projects, provide leads to promising approaches, and "take the lead risk"[47] for technology development.

The education technology unit supported a number of research and demonstration projects. Perhaps one of the most controversial was a comparison of ERE's technologically advanced "Talking Typewriter" and a "poor boy" version, which included a Smith-Corona typewriter, a Bell and Howell Language Master, and other components operated by an aide. This comparative study found that the "poor boy" version was 60 to 70 percent as effective as the Talking Typewriter, for a cost of $300 per station versus $30,000 to $40,000. The education technology unit also assisted in identifying sources within OEO for funding operational projects using computer-based education. Many of these projects were funded by Community Action Programs as "educational components". During 1965, of the total $120 million CAP program budget, $59 million was allocated to "education components" and 90 percent of the CAP programs had some educational components. Some of these projects supported R&D by Dr. O. K. Moore, Richard Kobler, and Dr. John Henry Martin. Much of Dr. Martin's early research has been incorporated into the current IBM Writing to Read program.

3. Closing Comment

Documentation about OEO-sponsored education technology R&D is minimal because of the political sensitivity of the projects and the unofficial nature of the support provided by OEO. Because of the flexible nature of OEO's authorizing legislation, OEO research and development "champions" had some discretion to address education technology. During the mid-sixties, contracting procedures were flexible; it was not unusual for the OEO contracting officer to increase budgets during contract negotiations. Proposal review and selection were often made in conjunction with Congressional committee staff, and the involvement of the private sector in both operational programs and R&D support was strong. Department of Defense influence and involvement of their "brightest and best" was prevalent.

However, given the enormous potential offered by OEO-supported programs to demonstrate the effectiveness of education technology, many opportunities

were missed as key "champions" left the agency and OEO began to lose its budgetary war to the Vietnam War. Those programs that were pursued ended at the demise of OEO during the early years of the Nixon Administration.

D. DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA): MISSION, MONEY, MAXIMUM FLEXIBILITY, AND MANAGEMENT

The Defense Advanced Research Projects Agency (DARPA) was established in 1958, in response to the Sputnik crisis, to explore high-risk, but potentially high-payoff, technology developments and to protect the United States against technology surprise. As Fletcher noted, "'Revolutionary not evolutionary' is supposed to characterize all DARPA projects. The agency's position is that if a project can be prespecified by a request for proposals, then DARPA should not be doing it".[48] During the late sixties and seventies, the director of DARPA, which had a staff about half the size of the National Science Foundation, reported directly to the Undersecretary for Research and Engineering. While most of DARPA's R&D support focused on air missile and space defense, according to Fletcher, "it has been the single-most influential government agency for the development of instructionally relevant capabilities such as computer speech interaction and artificial intelligence ... Most of this training research and development has hinged on computer applications".[49]

During the 1960-75 time period, DARPA funded a number of major projects related to computer-assisted instruction and artificial intelligence. As noted earlier, DARPA provided direct funding support and served as an umbrella for support from each of the services for the PLATO project (particularly PLATO III and PLATO IV). During the late sixties, DARPA also supported some path-breaking R&D in artificial intelligence at Stanford and MIT. Much of the subsequent research and development on artificial intelligence sponsored by the military services can be attributed to the initial DARPA support for Brown, Burton, and DeKleer related to SOPHIE.

During the late 1970s, research and development directly related to training, education, and human factors continued to be a DARPA priority involving leading sponsors. Other developments during the seventies and eighties can be attributed to initial support from DARPA. One such

development is interactive movies. Based on microprocessor-controlled videodisc technology, this technology allows viewer control over perspective, speed, detail, abstraction, sequencing, animations, etc. Another important development is "surrogate travel", which Fletcher[50] notes formed a new approach to local familiarization in low-cost trainers as it simulates movement over user-selected paths of travel. Another related area of development is a combination of surrogate travel and interactive movies which Fletcher refers to as "micro-travel". Another is spatial data management, which allows students to work independently on self-paced instruction by browsing through previously designed information spaces. DARPA has used videodisc technology to produce low-cost visual simulators such as the tank gunnery trainer. Other DARPA contributions include: computer-based authoring, learning strategies, and human skill acquisition and maintenance.[51]

During the 1980s, research has increasingly focused on large-scale networks, computer systems software development tools, tutoring systems, and human factors research involved in "embedded" training. One of the largest current R&D projects (SIMNET) focuses on simulation. Areas in which DARPA has made significant recent contributions include real-time image generation and simulators, networking of simulators, team behavior, and general development of learning curves for future simulation training developments.

1. Factors Contributing to DARPA's Success

There appears to be consensus on the factors which have contributed to DARPA's successful R&D program over the last three decades. DARPA, however, was "product" not "process" oriented (e.g., people were not hired to do research).

a. Mission

The DARPA mission to undertake high-risk R&D with long-term potential payoffs appears to have been critical to its success. Within most other DoD agencies and the military services, career considerations often precluded risky R&D activities, particularly in education and training. Indeed, the creation of the "6.3 line item", Advanced Development for Education and

Training, in 1965 was an attempt to provide opportunity for risky development and testing, although only the Navy took advantage of this item in the three years after the program's creation. The high priority of the DARPA mission was reflected in its position in the DoD hierarchy -- DARPA's Director reported directly to the Secretary of Defense.

b. Money

Since the 1960s, DARPA (originally ARPA) has allocated between one and two million dollars annually for R&D on computer-based education, training, and human factors. DARPA also allocated between two and four million dollars annually for indirectly related R&D, from which related payoffs accrued. According to some observers, from time to time during DARPA's history, behavioral science and human factor R&D had relatively low funding priorities; hence, the program has often had different titles (e.g., Office of Cybernetic Research in the 1970s) in order to disguise "human factors" R&D. The timing of funding was often more important than the level. As Farr[52] noted, "The implicit mission of DARPA was to fund important areas of R&D which the services overlooked or refused to support". Also, DARPA often provided "seed" or "risk" money to conceptualize an idea or initiated a small program which could then be funded collaboratively by other agencies.

c. Maximum Flexibility

Because of its "flexible" authority and management, DARPA was able to provide continuity, effective communications, and continuous support within its R&D community. The initial development and subsequent use of ARPANET provided unique opportunities for those on the network to exchange information including findings, "bounce ideas off experts", "refine thinking", and conduct other activities to increase the rigor of research and development. On the other hand, some observers felt that the creation and use of ARPANET for communications with colleagues reduced the number of print journal articles and traditional means of disseminating research findings to the general R&D community.

This flexibility also allowed DARPA staff to: (a) move quickly in support of key members of the R&D community at critical points; (b) serve as an umbrella for collaborative funding with the service agencies and other civilian agencies (e.g., NSF in PLATO); and (c) provide funding for symposia or travel for other agency staff (e.g., ONR) to attend critical meetings.

d. Management

DARPA's management and staffing philosophy was also important. DARPA actively sought highly qualified researchers and scientists, limited their employment to relatively brief periods (e.g., four to five years) to minimize empire building, and assumed that they would fund research among members of the R&D communities from which they came (and would likely return). DARPA managers provided administrative support for professional R&D staff with minimal bureaucratic red tape. A term at DARPA was considered a highly prized position for researchers.

DARPA's project management has been unique, with the project officer having unusual discretion and responsibility. During the sixties and seventies, few DARPA contracts followed the traditional competitive bid process, largely because some of the expected outcomes could not be adequately prescribed in Requests for Proposals and because of the collegial relationships between DARPA staff and the sponsor's research and development staff.

During the 1980s, more and more DARPA contracts were for applied R&D and were forced to follow the normal RFP process, a factor which many observers felt worked to the detriment of DARPA's primary mission. They argued that the procurement cycle was too lengthy and that procurement procedures for research and development must be quite different from those used to procure weapons systems.[53]

E. EDUCATION DEPARTMENT/OFFICE OF SPECIAL EDUCATION PROGRAMS: CATALYTIC, MULTIFACETED SUPPORT FOR TECHNOLOGY IN SPECIAL EDUCATION

The Office of Special Education Programs (OSEP) within the Department of Education (ED) has implemented a planned, multifaceted approach for supporting the creation of a market for special education technology. In operation for the last decade, the goals of this program have been to: (a) enhance the availability of instructional media, materials, and technology; (c) improve their quality; and (c) encourage their use. While relatively small (approximately $4-5 million annual budget), the Media Services/Technology Program (MSTP) has served the role of a catalyst, leveraging support from the private and public sectors, creating a client market demand, conducting appropriate research and evaluation and disseminating information. (Since Congress created new authorizing legislation for MSTP in 1986, the office is undergoing a possible name change.) The types of projects have included adaptation of hardware and communication aids and devices, adaptation of curriculum materials to meet specific needs, development of computer software, provision of assistance to state and local education agencies to plan, adopt, and implement new technologies, creation of technology information clearinghouses, and provision of market-related assistance to publishers, developers, and hardware vendors.

The growth of microcomputers and related technology in special education has increased at a faster rate than in education generally. In 1986, a survey of computer use in special education[54] found that the ratio of students to computers (shared and dedicated) in special education was approximately eight to one, while in regular education a similar ratio was approximately 30:1.

1. Brief History

In 1868, Congress created the American Printing House for the Blind, which has since been funded every year with a minimum annual budget of $10,000. Most support for the American Printing House has been from private firms and foundations. In 1958, Congress established Captioned Films for the Deaf, which was the first authorized program to support technology within the Department of Education.

Shortly afterwards, the Bureau for Education of the Handicapped (BEH) was created and the Media Research Branch was established. Over time, this branch has developed many films and instructional programs, established 65 captioned film depositories, supported the development and demonstration of the OPTACON and Kurzweil reader, developed interfaces for physically handicapped individuals, established media centers for the deaf, and supported numerous projects with the Childrens' Television Workshop.

As a former director of media-related programs stated, "In the early history of technology for the handicapped, we had a long-range and unified plan that moved from discovery of knowledge to the training of professionals and eventually to the acceptance and implementation of programs within classrooms".[55] BEH also developed a unique relationship with the private sector -- including publishers, hardware vendors, developers, and media producers -- supporting their efforts to produce and market products for the special education market, which most felt was too thin to enter without Federal assistance.

2. Current Program

Within this historical context and with the advent of the microcomputer, in 1980-81 a formal plan for technology was established with the ultimate goal of increasing the use of high quality instructional media, materials, and technology to meet the educational needs of handicapped children. As Yin[56] noted,

> "the attainment of this ultimate goal is <u>not</u> within the direct control of the Media Services/Technology Program. This is because the production of specific instructional media, materials, and technology is a function of private sector firms (e.g., textbook publishers, hardware manufacturers, and software developers) who are part of a much larger consumer marketplace and who operate independent of the program. Federally-sponsored activities can influence the marketplace to come degree, which is a major rationale for the Media Services/Technology Program ... program officials view the more appropriate role to be a catalytic one -- i.e., in making the marketplace work better rather than substituting for it."

The logic of the Media Service/Technology Program is displayed in Exhibit 9, based on an analysis conducted by Yin in 1986. The Media Services/Technology Program has remained consistent over this decade, as indicated by the types of projects it funded in 1981, displayed in Exhibit 10.

In addition to the "official" technology program, other OSEP activities during this decade have supported technology in varying degrees, often in close coordination with the Media Services/Technology Program. These include: (a) six regional resource centers which provide varying degrees of information dissemination and technical assistance related to special education technology; (b) teacher training programs, a portion of which covers training in the use of technology; (c) field-initiated and directed research and demonstration programs of which four large contracts have been funded at approximately $1 million annually to assess the effectiveness of technology; and (d) captioned films, which also include some technology-related research.

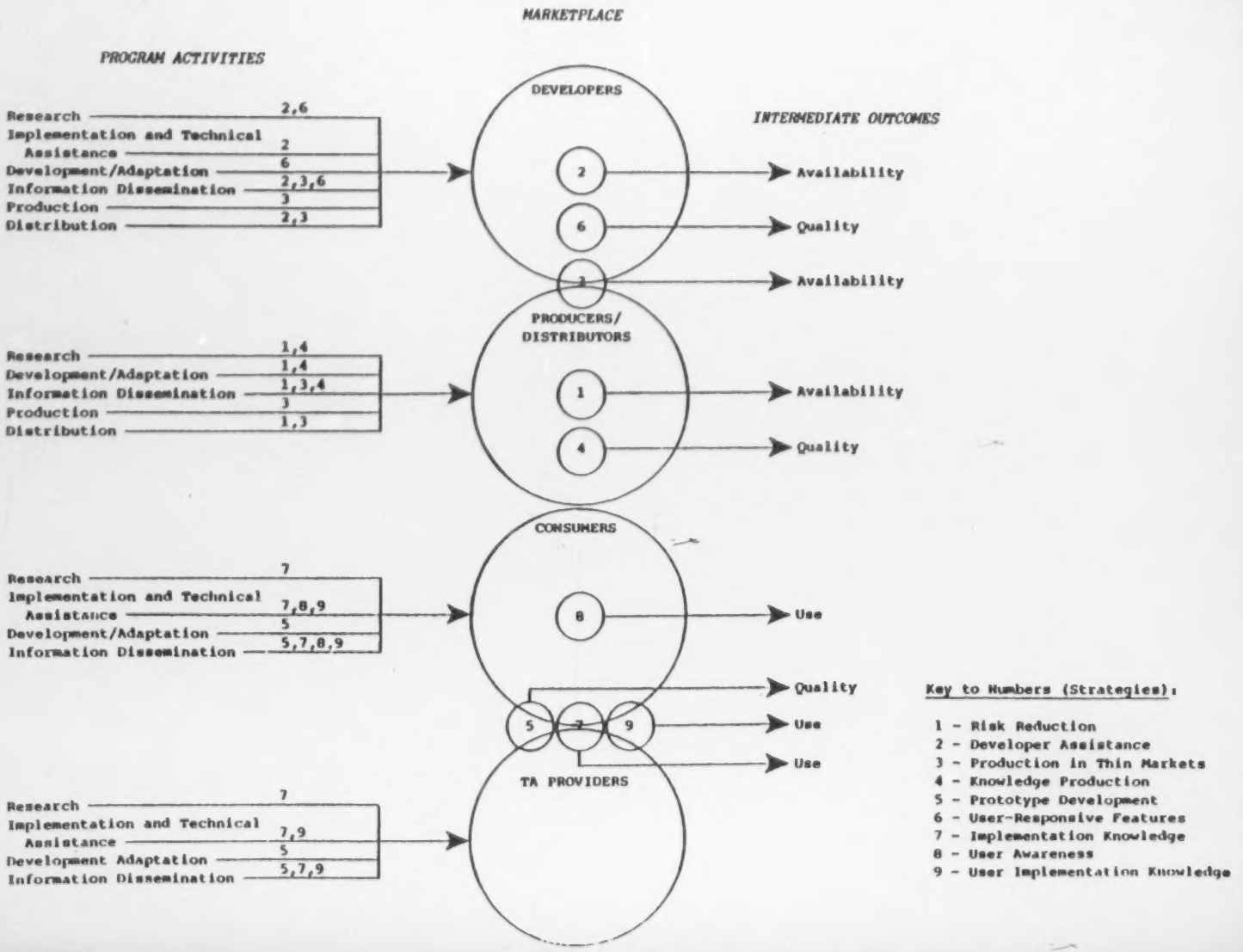
The ultimate impact of OSEP catalytic support for educational technology, dependent as it is to a large degree on the market mechanism, is difficult to assess. Three questions arise:

- Was the initial plan -- developed in the early 1980s -- followed?
- Was the program model valid?
- What are some indicants of the ultimate impact of increasing the use of high quality technology to meet the educational needs of handicapped children?

The evaluation of the program logic conducted by Yin found that the model was valid "in that the projects in the Media Services/Technology Program were mainly consistent with the model, <u>but</u> the model was not so global as to be applicable to all types of research or technology-related projects".[57] Moreover, "the funded activities were linked to a variety of intermediate and ultimate outcomes ... however, the extent of actual attainment of these outcomes was not well documented".[58]

Exhibit 9

RELATIONSHIP OF PROGRAM ACTIVITIES AND STRATEGIES IN THE MARKETPLACE



Key to Numbers (Strategies):

1 - Risk Reduction
2 - Developer Assistance
3 - Production in Thin Markets
4 - Knowledge Production
5 - Prototype Development
6 - User-Responsive Features
7 - Implementation Knowledge
8 - User Awareness
9 - User Implementation Knowledge

Exhibit 10

RELATIONSHIP OF MEDIA SERVICES/TECHNOLOGY PROCUREMENTS (1981-1982) TO PROGRAM OBJECTIVES/STRATEGIES

OBJECTIVES/STRATEGIES	1981-1982 PROCUREMENTS									
	1	2	3	4	5	6	7	8	9	10
I. AVAILABILITY										
A. Risk Reduction			x	x				x		x
B. Assistance to Developers		x	x				x	x		x
C. Commercial Sector Liaison			x				x	x		
II. QUALITY										
A. Competition			x			x		x		
B. Increase School Personnel and Handicapped Individuals Knowledge	x								x	x
C. Increase Developer Knowledge			x					x		
III. USE										
A. Access to Information on Technology Application	x				x				x	x
B. Strengthen Private Sector Marketing							x	x		
C. Enhance Capacity of Training and Technical Assistance Providers										

Procurement Legend:

1. Edutech
2. Deafnet Dissemination
3. Market Linkage Project for Special Education
4. Social Skills Curriculum
5. NASBE Special Education Dissemination Project
6. Curriculum Adaptation for Special Education
7. Materials to Help Ensure National Distribution of Teacher Made Materials
8. Analysis of Marketing for Educational Technology Software
9. Microcomputers in Schools
10. Assistance to LEAs to Adopt New Technologies

Source: "Goal Evaluation of the Media Services/Technology Program", Report prepared for the U. S. Department of Education, COSMOS Corporation, September 1986.

In addition to the higher rate of adoption and use of microcomputers in special education compared to regular education, which has to be attributed to some extent to MSTP's catalytic services, there are a number of other indicants of impact, including:

- creation of advanced degree technology training programs in leading universities;
- numerous state technology initiatives;
- the only ED-sponsored studies on the effects of computers in education in the eighties;
- well attended annual conferences and symposia; and
- information dissemination through supported centers to more than 65,000 requests.

3. Contributing Factors

According to knowledgeable observers, the success of OSEP's Media Services/Technology Program can be attributed to a number of factors, as discussed below.

a. Leadership

Officials responsible for technology-related projects and R&D support have been provided with solid leadership support within first BEH and now ED/OSEP. Division-level support for technology during the early 1980s was very visible and willing to undertake risky initiatives, including not only R&D projects and priorities but also bureaucratic entanglements with other programs and administrative procedures.

b. Legislative Authority

Authorizing legislation for the Media Services/Technology Program is in Part F of the Education for all Handicapped Act, as amended. It expanded Part F to cover not only captioned films, but also related research, development, training, production, acquisition (P.L. 87-715 in 1962), and educational media

and materials centers (P.L. 91-230 in 1970), among other initiatives. Later authority included Part F, Section 651(a)(2), Section 652(b)(5), and Section 653(a). The authoring legislation was flexible enough to include technology (even though the term is not mentioned in the Law) and provided officials with the flexibility to focus on the changing nature of problems and advances in technology during the 1980s. In 1986, after the program received little Congressional oversight, Congress created a separate Part G for the Media Services/Technology Program, which may result in more Congressional scrutiny.

c. Strategic Planning

Strategic planning for emerging electronic learning technologies began in the late 1970s. ED/OSEP commissioned the National Needs Assessment Study which identified growing interest in, and a pent-up demand for, emerging technologies such as computer-assisted instruction. It also commissioned a Study of the Cost of Special Education, which identified per-pupil expenditures for instructional material and equipment and related cost information. The results of these two studies were integrated into OSEP's overall strategic plan and provided extremely useful information for subsequent contractors who provided market-related research to the private sector.

d. Institutional Arrangements

The major participants and beneficiaries involved in the technology program are:

- research and development groups including universities, private firms, and schools;
- hardware manufacturers, software publishers, and distributors of technology products;
- users including school staff, parents, and students; and
- providers of technology assistance and training.

(1) Researchers and Developers. During the early 1980s, most MSTP development projects were performed by not-for-profit organizations and

universities. The field-initiated and other grant programs precluded participation by profit-making firms. When the technology program began to contract for the adaptation of existing materials, developers were required to team with potential publishers and/or distributors of the resulting products. In some instances, intermediary firms became prime contractors because many private developers/publishers could not or would not accept ED's cost-plus-fixed-fee reporting and auditing requirements.

During 1983-84, when a relatively high percentage of ED/OSEP funds were allocated to the Small Business Innovation Research (SBIR) program, the number of private developers and publishers increased dramatically. The SBIR program was viewed both within ED/OSEP and among developers as a solution to another major problem within the MSTP -- the lengthy planning and procurement process which often resulted in priorities and/or specifications that were technologically outdated by the time RFPs were announced. Moreover, this program encouraged developers to propose innovative products based on their assessment of the marketplace and consumer needs rather than on priorities established by ED program officers.

The MSTP, for the last four years, also has provided continuing support for four research contracts with a total annual budget of $1 million to assess the effects and effectiveness of computers and related technology use in special education and to identify alternative ways of integrating technology into curriculum areas. Most of these performers have been universities.

Communications with the R&D community occurred on an informal basis during the early eighties; the first formal R&D symposium was held in 1984. These annual symposia have facilitated sharing of information among the R&D community, and between ED/OSEP and the R&D community, regarding priority issues and have provided opportunities for generating support for the program. While the symposia have been considered successful by most people, others have argued that they have reinforced the closeness of the special education R&D community, excluding new ideas from the "outside".

Another activity provided by third-party contractors is the Special Education Software Center, which was designed to provide technical assistance

to software developers, among its other functions. In its three years of existence, developers have not taken full advantage of the Center's services for a variety of reasons. As Yin noted, "the technical assistance portion of the technology software center assumed that developers (who were in fact consumers) were in need of final polish to their programs; few such developers in fact requested help from the center. One possibility is that, as consumers, these persons had other priorities that needed to be overcome before the development of any software".[59] Under a previous contract, the Market Linkage Project for Special Education (MLPSE) also provided technical assistance and legal guidance to developers of various media products, including some which were computer-based. Few technology-based developers took advantage of this service either.

(2) Hardware Vendors, Publishers, and Distributors. Institutional support arrangements with hardware vendors, software publishers, and distributors have generally been indirect. The largest program supported over the past decade has been the MLPSE which, in addition to providing technical assistance to developers, assisted in developing individualized marketing plans with publishers and licensing products (developed under other ED/OSEP programs) to publishers. The MLPSE has been the focus of two studies during the 1980s to redirect its efforts toward technology. In 1986, 20 technology-related products had been licensed and 73 individualized marketing plans developed with publishers. During the early 1980s, Project TechMark was implemented with an underlying goal of encouraging software publishers and developers to enter the special education market. A Market Profile Report was prepared and requested by approximately 500 publishers; during TechMark's 18-month existence, the number of software publishers with announced products for special education teachers and students increased fourfold.

The Media Services/Technology Program has also facilitated, through sponsorship of conferences, direct personal communications among users, publishers, and developers. One of the most successful activities sponsored by the software center over the last three years has been the annual Special Education Software Conference, which was designed to facilitate effective communications with regard to product needs.

Even though the MSTP attempted to support publishers in the development and adaptation of software to meet special education needs, few such projects have been undertaken. Many software publishers do not have accounting systems compatible with government contracting requirements, nor do they wish to open their books for government audits. Most such firms do not have adequate staff to develop comprehensive government proposals and, when they do submit, they usually have intermediate contractors. The long-term nature of such projects -- often two and a half to three years in duration -- make most education software publishers anxious about the volatility of the industry. Indeed, one of the major problems in one of the projects in which a developer and publisher were jointly funded was the acquisition of the publisher by a third party.

In spite of the difficulties in supporting publishers directly, the number of software titles identified for potential use by special education teachers and students has increased from less than 100 "quality" titles in 1983 to more than 250 titles in 1986.[60] According to many software publishers, special education is considered one of the growth markets in education today.

(3) **Consumers and Users.** Most institutional arrangements with consumers and users have been through intermediary contractors. Primary services have included information dissemination, technical assistance, and training. Perhaps the largest and most valuable service has been an Information Center for Special Education Technology. The Center has responded annually to between 12,000 and 20,000 requests for information from teachers, parents, and other interested parties.[61]

(4) **Training and Technical Assistance Providers.** Many of the technical assistance and training projects supported by the MSTP have served other purposes. The SpEd Tech project, funded in the early 1980s, was officially designed to help schools adopt technology. However, through the use of regional workshops involving a sample of special educators across the country, needs assessment information was obtained to assist ED/OSEP in their planning. This project also attempted to expose software publishers to the special education market through demonstrations and exhibits. Another major

technical assistance project was subsequently funded, not only to assist large urban districts in adopting technology, but also to document and analyze the adoption process.

(5) Strengths and Weaknesses of Institutional Arrangements. A major strength of the MSTP has been its communications and dissemination activities. Although provision of technical assistance to developers was only moderately successful, formal and informal communications between the program and developers have allowed for cross-fertilization of ideas among developers. Information dissemination, particularly regarding market factors, was extremely useful to publishers, software publishers, and vendors and contributed significantly to increased entry into the special education market. Contractor-operated information centers on special education technology have proven to be effective for client and consumer groups, and the annual software conference is considered extremely useful in facilitating communications among users, publishers, and developers.

e. Procurement

The Media Services/Technology Program has the flexibility to use both contracts and grants and was the first office within ED to experiment with cooperative agreements. While legislation precluded participation by for-profit organizations in certain technology-related grant programs (e.g., field-initiated studies), small businesses were provided unique opportunities for development projects under the SBIR program. Unlike traditional grant and contract procedures, which generally were not sufficiently flexible to accommodate advances in technology, procedures under the SBIR program allowed contractors to redirect efforts based on changing needs and technology while minimizing administrative burden.

While flexible procurement instruments have been a strength of the overall procurement process, other procedures used by the Department of Education have constrained the quality of R&D support for technology. The lengthy procurement process between planning and contract award -- often over a year and a half -- has frequently resulted in development efforts which could not take advantage of the state-of-the-art in advanced technology. To

bypass this lengthy process, a large number of 8-A/minority set-aside contracts (which can be awarded in a matter of weeks) were used in ED/OSEP, including several by MSTP.

"Peer review" is an important element of MSTP procurement activities. For directed R&D projects, RFPs require the use of advisory committees by contractors. On one hand, this ensures balanced perspectives; on the other hand, because of the limited number of experts in the special education R&D community, the same individuals appear in multiple proposals. Proposing advisory group membership often becomes ritualistic and time consuming. In other technology-related programs such as field-initiated research proposals are reviewed by peers.

Some observers have argued that, because of the small number of experts in the special education R&D community and recent constraints on travel for peer reviewers, the most qualified individuals are not necessarily picked for the peer review process. Many such experts submit their own proposals, creating potential conflict-of-interest situations.

While the funding authority is flexible in support of technology R&D activities, OSEP priorities in RFPs are frequently difficult to understand unless one has prior knowledge of the procurements.

As some observers have noted, special relationships exist between a number of principal investigators/project directors in the R&D community and program and OSEP staff, and that incumbents have considerably greater access to information than do outsiders. While some observers argue that this results in preferential treatment for incumbents, others state that "the principal investigators appear to have a good understanding of the Media Services/Technology Program's goals for their projects, and these people play an essential role in keeping projects on the right track".[62] Just as it is difficult for a non-special educator to break into the close-knit special education community, it is equally difficult to enter the special education R&D community.

f. Funding

In 1985, there were approximately 45 active projects relating to technology and marketing in special education. Eighteen involved software development adaptation and integration, and a similar number involved hardware development and adaptability. Eleven of the projects related to information gathering and dissemination to educators, including development of teacher guides, training modules, telecommunication networks, and resource centers. The size of the projects ranged from seven of more than $400,000 annually for three years to one-year projects for approximately $75,000. The larger, long-term contracts were directed efforts to provide information, to provide market linkages with publishers, and to conduct research on the effects of technology use in special education. The smaller projects had development and adaptability foci. Since 1980, the technology program's annual appropriation has been between $4 million and $5 million. This level of official support, plus additional funding for the other OSEP programs which have supported technology R&D and training programs, has fostered a level of continuity unique in the Department's history.

F. LOGO: FEDERAL R&D TO ADOPTION -- A LENGTHY PROCESS

LOGO is a computer programming language designed for children. Among all the technology developments designed for educational purposes, LOGO may have had more impact on learning and teaching than any other single development. The 20-year history of LOGO research, development, and dissemination illustrates several key characteristics of the nature of educational technology R&D and the Federal role in this enterprise.

1. Historical Events in Development and Dissemination of LOGO

LOGO was created in 1966 at Bolt Beranek and Newman (BBN), a Cambridge research firm.[63] Its intellectual roots are in artificial intelligence, mathematical logic, and developmental psychology. During the early 1960s, BBN had become a major center of computer science research and innovative applications. Wallace Feurzeig joined the firm in 1962 to work with its newly

available facilities in the Artificial Intelligence Department, one of the earliest AI organizations.

Feurzeig's initial focus at BBN was on expanding the intellectual capabilities of existing teaching systems. This led to the first "intelligent" computer-assisted instruction (CAI) system, MENTOR, which employed production rules to support problem-solving interactions in medical diagnosis and other decision-making domains. In 1965, Feurzeig organized the BBN Educational Technology Department to further the development of computer methods for improving learning and teaching. The focus of the work then shifted to the investigation of programming languages as educational environments. This shift was partly due to two technological advances: the invention of computer time sharing and the development of the first high-level "conversational" programming language.

Time sharing made feasible the economic use of remote distributed terminals and opened up the possibilities of interactive computer use in schools. BBN had recently implemented TELCOMP, one of the new breed of high-level interactive programming languages. TELCOMP was a dialect of JOSS, the first "conversational" (i.e., interpretive) language, developed in 1962-63 by Cliff Shaw of the Rand Corporation. Shortly after TELCOMP was created, Feurzeig and his colleagues decided to introduce it to children as a tool for teaching mathematics. In 1965-66, with U. S. Office of Education support, they explored its use in eight elementary and secondary schools served by the BBN time-sharing system. Students were introduced to TELCOMP and then worked on standard arithmetic, algebra, and trigonometry problems by writing TELCOMP programs. The project strongly confirmed their expectation that the use of interactive computation with a high-level interpretative language would be highly motivating to students.

From 1963 to 1968, Feurzeig had a contract with the Office of Naval Research to develop new computer systems for teaching complex concepts. Dr. Feurzeig approached Glen Bryan, the contract officer at ONR, with the idea of developing a programming language for children. Although the contract with ONR was not for the purpose of working with young children, Dr. Bryan said it would be acceptable to work with children if the work was done at a military

dependents' school. Thus, the first work with children, and what was to become LOGO, was done in 1967 at Hanscom Field School in Lincoln, Massachusetts.

In the summer and fall of 1966, the first version of LOGO was designed and implemented at BBN under the same ONR project. This implementation was for the Scientific Data Systems SDS-940 computer. Early ideas for the design of the new language were developed in collaboration with Seymour Papert. Papert, who was then a research associate at MIT, worked at BBN as an educational research consultant. The central notion was that of a procedural computer language having transparent calls to other procedures, simple enough for children to learn yet powerful enough for expressing important intellectual content. Papert specified the overall functional form of the new language, which was named LOGO by Feurzeig. Daniel Bobrow of the BBN Artificial Intelligence Department made extensive contributions to the initial design and implementation, together with Papert and Feurzeig. Others in the BBN LOGO group at that time included Frank Frazier, Richard Grant, Charles R. Morgan, Cynthia Solomon, and Paul Wexelblat, all of whom contributed to LOGO design, development, and implementation. Interestingly, although LOGO was intended to be very easy to use by young children, it was based on Lisp, considered by non-Lisp programmers to be one of the most difficult of programming languages to learn.

At the Hanscom Field School, this first version of LOGO was used in teaching fifth and sixth grade math students. The project goals were to investigate the ease with which students learned and used the new language and to explore ideas for teaching with it.

In 1967-68, a new and greatly extended version of LOGO was designed and implemented on the BBN DEC PDP-1 computer system. During the period September 1968 through November 1969, the National Science Foundation supported the BBN project "Programming Languages as a Conceptual Framework for Teaching Mathematics". This project involved an intensive program of experimental teaching of LOGO-based mathematics in elementary and secondary classrooms. The work included teaching of second and third grade children at the Emerson School in Newton, Massachusetts and of seventh graders at the Muzzey Junior

High School in Lexington, Massachusetts. The project was designed to explore the problems and potential benefits from the use of LOGO by very young children and to investigate the effectiveness of LOGO in improving the learning and teaching of algebra with students with low to average mathematics ability.[64] The 1969 program announcement for NSF's Computing Activities in Education described the project in this manner:

> "A project designed to explore fundamental curriculum revision at the elementary school level is directed by Wallace Feurzeig of Bolt, Beranek & Newman in Cambridge, Massachusetts. The goal is to demonstrate through classroom presentations that the teaching of the set of concepts related to programming can be used to provide a natural foundation for the teaching of mathematics, and indeed for logical thinking in general. A new programming language permits the expression of mathematically rich algorithms, both numerical and nonnumerical, but is so simple that it can be taught to second graders."[65]

When Feurzeig approached Milton Rose, the program manager of the OCA at NSF with the idea, Rose objected that NSF funded only universities, not companies like BBN. Feurzeig replied that: (a) the work is very important, and (b) no one else can do it. Rose agreed.

In 1968-69, a class of 12 seventh grade students at the Muzzey Junior High School in Lexington, Massachusetts worked with LOGO through the whole school year. At that time, the LOGO system had no graphics. Pioneer work in using the Turtle to teach very young children was done by Radia Perlman who demonstrated that four-year-old children could learn to control mechanical Turtles.

In 1970-71, a second BBN project "Programming Languages as a Conceptual Framework for Teaching Mathematics" was supported by NSF (Contract NSF-C-651). This project was directed at the development of a number of extended LOGO-based mathematics curriculum materials in areas including arithmetic, algebra, analysis, logic and problem-solving strategies. The materials were developed to show the great scope of application of LOGO to virtually all areas of mathematics, to exemplify the variety of approaches and styles supportable, and to provide ideas and exemplify models for prospective teachers and curriculum designers.[66]

Some of this early work on LOGO at BBN was also supported by ARPA. The ARPA support was part of a several-component project called "Information Processing Models and Computer Aids for Human Performance" administered by AFOSR, Scientific Research Contract F44620-67-C-0033. The LOGO-related work was done as Task 3: "Programming Languages as a Tool for Cognitive Research." The BBN report was written in June 1971.

In 1970, BBN designed and wrote the first version of LOGO for the DEC PDP-10 computer, a system widely used in universities and educational research centers. A DEC-10 LOGO Reference Manual describing this version was produced in June 1971. Throughout 1971-74, BBN distributed DEC-10 LOGC to those universities and research centers requesting it for their own research and teaching, without charge. BBN provided a copy to MIT in September 1970, with subsequent revisions in 1970 and 1971.

From 1969 until the present, organizations other than BBN, including Stanford University and MIT, began to implement their own versions of LOGO. The first such version, SLOGO (for Stanford LOGO) was documented in May 1969.

NSF continued its support for LOGO research and development throughout the 1970s and into the present. It supported work not only at BBN and MIT, but at other centers of LOGO research as well. A partial list of supported projects is provided as Attachment A.

Since 1971, Papert and other LOGO researchers have been publishing articles and books which have brought LOGO to the attention of both the educational research community and classroom teachers. Some of these articles are listed as Attachment B.

From MIT, the LOGO language spread to other academic centers around the world. A major research project in Scotland was shortly followed by others in Australia, Canada, and Germany with substantial interest shown by other countries in Europe, the Middle East, and the Orient. The Edinburgh LOGO Project at Department of Artificial Intelligence, University of Edinburgh, Scotland, dealt with 12- and 13-year old boys attending a private school adjacent to the university. It focused on the use of LOGO to create an

environment for learning to think mathematically and on developing new methods to teach the content of conventional school mathematics.

During the 1977-78 school year, four computers equipped with LOGO and Turtle Graphics were installed in an elementary school in Brookline, Massachusetts. All sixth grade students in the school had between 20 and 40 hours of hands-on experience with the computers. The work of 16 students was documented in detail.

The second Brookline LOGO Project in 1979 was also funded by the NSF to develop a curriculum supporting classroom use of LOGO. In 1982, the MIT LOGO Group sought a commercial publisher for them in accordance with the requirements of the National Science Foundation. Actually, these materials never were published because of several timing factors related to the ambiguous status of the rights to LOGO, the fact that educational publishers were uncomfortable with this radical new educational innovation, and the lack of leadership at MIT upon Papert's leaving to participate in a project in France.

In 1980, the Lamplighter School project began with support from Texas Instruments and the MIT LOGO group. The school was provided with 50 TI LOGO systems used throughout the grades. The goal of the project was to establish a setting in which student access to computers would not be a limiting factor and to see what students could learn in such circumstances.[67]

In early 1981, MIT was making available a beta test version of LOGO for the Apple computer. Later in 1981, Apple Computer Inc. distributed Apple LOGO for the Apple II+ computer system, thus making it available on the most popular microcomputer in schools. Several other versions of LOGO for microcomputers rapidly appeared on the market. In 1982, Cybertronics released low-cost LOGO for Apple II. Cyberlogo was the first one for the Apple II that did not require a language card; it only required 48K RAM.

In 1982, Dan Watt's article noted,

> "During the past year, the use of LOGO in schools has jumped from less than a dozen sites to hundreds. By the end of the coming year, it may involve thousands of classrooms with tens of thousands of students. As we struggle with the task of integrating new forms of learning into old structures, we should be particularly aware of the opportunity to learn from each other and from the limited but carefully supported research and development that have already occurred."[68]

By 1982, there were at least six LOGO-oriented newsletters.

In 1986, two major new versions of LOGO -- LOGOWriter and Lego LOGO -- appeared on the market, greatly expanding the scope of LOGO applications. Recently, LCSI site-licensed all elementary schools and most middle schools in Minnesota for use of its LOGOWriter. LCSI has now developed 23 versions of LOGO in eight foreign language translations on 13 different microcomputers. There are now over 60 book titles on the subject of LOGO and dozens of curriculum packages for teaching LOGO.

2. Lessons Learned

LOGO is a good example of the difficulties of funding innovative ideas within traditional educational program structures. Andy Molnar at NSF noted in the mid 1970s that it was hard to get LOGO work funded through the Science Education programs because mathematics educators did not regard the work as valid mathematics and computer science educators did not regard it as valid computer science.

The early funding of LOGO research and development by Office of Naval Research and then predominantly by the NSF was a high-risk undertaking in terms of possible payoff, although the amount of funding was not unusually great compared with other projects of the time. First, the idea of young children working with computers was a radical idea in the late sixties, when computers were very expensive and few students even in high school had access to them. Secondly, LOGO's theoretical basis in Piagetian child development was a radically different paradigm for computer use in instruction from the prevailing paradigm of behavioral psychology and teaching machine use of computers. Thirdly, the concepts of mathematics and mathematics learning

embodied in the turtle graphics of LOGO were a major departure from conventional math education. Throughout the research and development LOGO projects in the 1970s there was never a clear "fit" between LOGO activities in school and the traditional curriculum. Fourthly, LOGO research was always plagued by methodological problems in terms of evaluation. Indeed, there never was a systematic evaluation of the effectiveness of LOGO as a tool for learning problem solving, math, or any of the other kinds of learning claimed for it.

BBN was atypical of the kind of institution normally supported by NSF (universities) at that time. Thus, there are many reasons why LOGO would not have been supported, unless the funding agency had a great deal of flexibility and its program managers had vision and a long-term perspective.

LOGO research and development has received nearly continuous support from the NSF for nearly twenty years, in spite of the vicissitudes of changing missions, budgets, and organizational structures. This illustrates the critical role of dedicated program managers who persist in pursuit of their vision and protect a line of research they believe to be important.

The theoretical and technological underpinnings for LOGO research were the synergistic result of collaboration among highly talented people from diverse backgrounds -- developmental psychology, artificial intelligence, mathematical logic, physics, engineering and computer science. Both the parent organizations, BBN and MIT, had multidisciplinary groups that transcended traditional boundaries, even within their own institutions. At MIT, for example, the LOGO group was part of the Artificial Intelligence Laboratory which did not have a "home" in one of the traditional academic departments at MIT. Similarly, funding agents had to depart from traditional disciplinary boundaries in supporting this work.

Every stage of research and development of LOGO involved work with children in classrooms in various schools and school districts. Thus, even though the classes were not typical of mainstream classrooms in their content and conduct, the involvement on a day-to-day basis of the children and their teachers contributed to the progress.

Throughout the period of LOGO's evolution, there have been many dramatic changes in the hardware and software state-of-the-art. Each new evolutionary stage in LOGO's development was implemented on a newer and better computer. LOGO researchers were in a position to take advantage of new technology capabilities at each stage, because they were working in technology-rich environments that included people with the expertise to take advantage of new technology developments. Thus, lack of appropriate technology base was never an obstacle to the progress of the work.

LOGO has had a lasting impact on education world-wide. Its pedagogical philosophy of constructionism and children's control over technology has greatly influenced education in general and educational computing in particular. It has made control over computers accessible to millions of children and teachers, in a way that no other single tool did or could have. It has helped to encourage the priority on problem solving in many school districts. It has spawned a virtual industry of books, curriculum guides, software, teacher workshops, and other products. It has provided a model for further research and development of software microworlds and other intellectual tools for children.

Attachment A: Partial List of NSF Grants for LOGO R&D

The LOGO project could not have happened without support of the National Science Foundation which supported the work on LOGO since its inception. "I want to mention some of the Foundation's individuals whose imaginative understanding made it possible for us to do our work: Dorothy Derringer, Andrew Molnar, and Milton Rose". (Papert, Mindstorms)

NSF Grant GJ-32222, the LOGO Project at Syracuse University started in 1971. "The NSF grant allowed us to build up our staff to six full-time research assistants, and to acquire the use of sufficient hardware and computer time to launch our most serious and controlled look yet at the LOGO experience." Equipment included a PDP-10 and four terminals and the computer-driven turtle, a robot consisting of a pair of stepping motors, and several bells, whistles, and control wires mounted on a piece of plexiglas with a clear dome-shaped plexiglas cover. There is a pen which can be used to draw while the turtle is moving. Twenty-six children participated in the LOGO classes.

LOGO Memo 8: June 1973. Uses of Technology to Enhance Education, by Seymour Papert. This paper is the substance of a proposal to the NSF for support of research on children's thinking and elementary education. This work was supported by the NSF under grant GJ-1049 and conducted at the Artificial Intelligence Laboratory.

The 1974 Computers in Schools Project developed by the New York Academy of Sciences in conjunction with the New York Chapter of the Association for Computing Machinery, Dr. Seymour Papert, and the LOGO lab at MIT and in cooperation with Texas Instruments. Goals of the project included the implementation of child-appropriate computer systems and languages in the New York City Public Schools; providing a model design for teacher training. Teacher training component began in the summer of 1980 with a three week summer institute to train 11 elementary and junior high school teachers and an elementary school principal from the three public school districts and three teachers from the Bank Street School.

NSF award 9/23/77 $180,700 "Assessment and Documentation of a Children's Computer Laboratory" to Seymour Papert, MIT. This 12-month project documented the experiences of a small number of fifth grade children in an elementary school computer laboratory, using LOGO. Detailed anecdotal records were kept, and observers noted the development of the children's computer programming skills and the acquisition of knowledge in the areas of mathematics, science and language, and of cognitive strategies and attitudinal changes which transfer beyond the specific subject matter studied.

NSF award 4/1/77 $136,912 "Dissemination of LOGO-Based Educational Research" to Wallace Feurzeig, BBN. Implemented logo on a variety of small computers.

NSF awards to Papert before 1980, "LOGO Methods in Science Education using Low Cost Home Computers", "Interest Worlds: Precollege Mathematics in a Computer Culture."

NSF grant under RISE 77-19083SED, to MIT -- Brookline LOGO Project Seymour Papert, Dan Watt, Andrea diSessa, Sylvia Weir.

NSF grant number SED-7919033. (second Brookline project) 1979.

The Computers in Schools Project in New York City (1981) received funding from the NSF. The goal was for eight new teachers to be trained in each of the three school districts with the initial group of teachers acting as trainers.

NSF award in 1985 of $351,904 to the Institute for Schools of the Future, City College, CUNY. "Model schools of the future: unlimited access to computers leads to new ways of teaching and learning mathematics and science". Learning environment for junior high school students based on the LOGO computer philosophy. NSF award FY 86 $196,359 + 146,359 + 50,000 + FY 88: $106,183 to David Klahr at Carnegie Mellon University for "LOGO Debugging Skills: Analysis, instruction and assessment."

NSF award in 1985 of $274,321 to Emory University, "Teaching and Understanding Geometric Relationships through LOGO."

NSF award in 1985 of $317,086 and 1986 $260,982d to Lesley College. "Intelligent LOGO Tools for Algebraic Problem Solving."

NSF award FY 86 $331,705 and FY 88 $195,352 to Douglas Clements and Michael Battista, Kent State University. "Development of a LOGO-Based Elementary School Geometry Curriculum"

1986 NSF $196,359 and 1988 $106,183 to Carnegie Mellon University. "LOGO Debugging Skills: Analysis, Instruction and Assessment"

Attachment B: Some Classic LOGO Publications

In 1971 the classic Papert and Solomon article was published as an MIT memo: "Twenty Things to do with a Computer." (AI Lab Memo #248, LOGO Memo #3, MIT, 1971). Another memo by Papert which drew the LOGO development to the attention of researchers was LOGO Memo 2: Teaching Children THinking, (Seymour Papert, Oct. 1971).

1976 du Boulay and O'Shea, "How to Work the LOGO Machine: A Primer for ELOGO". Occasional paper No. 4, Dept of Artificial Intelligence, University of Edinburgh.

1976 LOGO Memo 22: LOGO Progress Report 1973-75, Ira Goldstein, Seymour Paper, Hal Ableson, Jeanne Bamberger. "Over the past two years, the LOGO Project has grown along many dimensions. This document provides an overview in outline form of the main activities and accomplishments of the past as well as major goals guiding our current research. Research on the design of learning environments, the corresponding development of a theory of learning and the exploration of teaching activities in these environments is presented."

1976 LOGO Memo 26: An Evaluative study of modern technology in education (proposal to the NSF) by Seymour Papert, June 1976. This proposal to the NSF describes a new phase of research planned in LOGO. Previous phases have concentrated on developing a conceptual superstructure (theories and teaching methods) and a material infrastructure (hardware and software) for a new style of using computers in education."

1976 LOGO Memo 29: Student science training program in mathematics, physics, and computer science, final report to the NSF, Hal Abelson and Andy diSessa, September 1976. "During the summer of 1976, the MIT AI lab sponsored a student science training program in mathematics, physics, and computer science for high ability secondary school students. This report describes, in some detail, the style of the program, the curriculum and the projects the students undertook. We hope that this document can serve not only as a report to the NSF but also as an elaboration of our ideas about what would constitute a model educational environment for high ability secondary school students."

1978 LOGO Memo 51: Information Prosthetics for the handicapped. Seymour Papert and Sylvia Weir, September 1978. "In this proposal to the BEH we describe a technological step towards the realization of information prosthetics. Our primary focus is on using rather than making the technology. Specifically, our goal is to transpose for the use of cerebral palsied children a computer based learning environment we have developed, and to study in this environment a series of issues in developmental psychology, psychology of learning, in psycho-diagnostic techniques and in methods of instruction.

1979 book by Paul Goldenberg, Special Technology for Special Children (Baltimore: University Park Press) presents the philosophy, psychology and technology behind his work in applications of LOGO for education and rehabilitation of children with severe communication handicaps.

Mindstorms, by Seymour Papert, published in 1980.

1980-81 Computing Teacher. Article by Sylvia Weir and Dan Watt of the LOGO Group at MIT. "LOGO: A Computer Environment for Learning Disabled Students."

1981 Harold Abelson and Andrea diSessa's book Turle Geometry: The Computer as a Medium for Exploring Mathematics. Cambridge, MA: MIT PRess.

1982 BYTE magazine special issue on LOGO. Five versions of LOGO compared: TI LOGO for the Texas Instruments TI-99/4; Apple LOGO, Krell LOGO, and Terrapin LOGO, all fro the Apple II and Apple II Plus; and Color LOGO from Radio Shack for the TRS-80 color computer. 1983 "LOGO's Limits: Or Which Language Should We Teach?" article by bob Tinker in Hands On!

G. TECHNOLOGY TRANSFER FROM DoD TO CIVILIAN EDUCATION APPLICATIONS: MIXED RESULTS

Over the last three decades, education technology transfer has been a major policy concern within DoD in at least two contexts: (a) the transfer of R&D products and concepts into practice within the service training commands; and (b) transfer of DoD education and training R&D products into civilian education. The McNamara directive in 1965 and the Air Force policy letter which assigned education and training R&D responsibilities to the Air Training Command were two early attempts to resolve problems related to DoD internal technology transfer, as discussed earlier in this paper. The purpose of this "case study" is to: (a) describe briefly the history of policy initiatives within DoD and other agencies to transfer DoD R&D (and resulting products) to civilian education and training applications; and (b) assess their impact and factors which contributed to the mixed bag of successes and failures.

Technology transfer from DoD can be classified into two categories: (a) formal policies involving other Federal agencies; and (b) informal initiatives involving nonpublic agencies and individuals.

1. Formal Technology Transfer Involving Federal Agencies

In the mid-1960s, Secretary of Defense McNamara, Assistant Secretary Tom Morris, and other high-level OSD officials argued that the DoD could be a test bed for advanced development and testing of technologies, providing opportunities for spinoffs into the civilian sector. Indeed, Secretary McNamara sent another directive to the military services in 1967 instructing them to copy and distribute, upon request by any nonprofit educational institution, nonclassified materials, films, CAI programs, etc. which they had available. Most of the services felt this activity was beyond their missions and were hesitant to allocate funding and high-level support to it.

In the early seventies, the U. S. Office of Education attempted to develop a working relationship with DoD, assigning coordination responsibilities to the Associate Commissioner for Vocational Education.

Concurrently, the Aerospace Education Foundation began to explore the possibility of converting specific training and educational materials to civilian use and subsequently received a contract from the U. S. Office of Education to do so. Most materials involved the use of instructional television in training areas such as electronics. Some of these products were field-tested in large-scale operations such as the community college system in Utah.

In 1973, under the leadership of Dr. William Pierce, a task force was created to develop a component of the U. S. Office of Education which would focus on technology transfer. USOE began to look for a lower cost alternative to the Aerospace Education Foundation, which was charging $60,000 per product for adaptation and marketing.[69] The task force met with Navy officials to review a variety of materials and training devices to identify specific opportunities for the conversion process. USOE wanted to establish procedures which would not only facilitate the conversion of DoD products and packages for civilian use, but also ensure that both DoD and civilian products (mostly videotapes and films) would be produced at the same time to take advantage of economies of scale. In the mid-seventies, a joint task force was established between USOE and DoD, represented by the Navy. Over time, however, this task force dissipated because of the low priority placed on its activities by the military services.

According to Chatelier,[70] during the early 1980s, largely at the prompting of the Department of Commerce, technology transfer from defense to civilian sectors once again became a priority within OSD. However, in the 1980s as interest increased on the civilian side (including Congress), some Defense officials thought that the establishment of a large, formal technology transfer program would result in loss of control to the Department of Commerce. Implementation within DoD has thus been minimal. On the other hand, in the education and training area, technology transfer from laboratories to operational use continued as a major issue. While early attempts during the eighties were made to centralize and formalize technology transfer activities within DoD, political support for this activity eroded. As a result, most technology transfer initiatives have been relegated to the three services.

Formal interdepartmental initiatives to facilitate technology transfer into education have clearly not worked, largely due to inadequate policy implementation usually revolving around lack of funds and bureaucratic wrangling. Several observers of the process identified a number of important conditions under which such a formal program could be successful:

- legislation mandating a program and participation by specific departments and agencies;
- establishment of offices responsible to the Secretary or Undersecretary in the participating departments;
- the creation of a line item in each of the participating departments' budgets for technology transfer;
- appropriate levels of funding for both administration, promotion, and dissemination activities within non-DoD agencies; and
- appropriate funding to cover marginal costs of adaptation of materials and products.

2. Informal Initiatives

Technology transfer from DoD to civilian education environments has most successfully resulted from informal initiatives on the part of DoD R&D staff and/or the R&D community, or through serendipity.

The untimely closing of the Air Force Personnel Training Research Lab in 1955 resulted in the largest single cadre of programmed instruction expertise in the country being dispersed to private industry, universities, and other groups, all of which had a major impact on innovative activity in this area during the next decade or so. Beyond this incidental diffusion of talent, a number of conscious initiatives appear to have had some major impacts.

Knowledge transfer among Federal R&D supporting agencies has been greatly facilitated by a number of DoD initiatives, including: (a) joint collaborative funding of various agencies of broad-scale R&D projects (such as PLATO) which have often been initiated by DoD; (b) convening of national conferences (e.g., NSIA, ARISTOTLE), particularly those initiated and/or sponsored by the Office of Naval Research; and (c) sponsorship of other

dissemination activities such as ONR's funding of the ENTELEK, Inc. state-of-the-art surveys on CAI during the sixties and early seventies.

Collaborative efforts between DoD and certain contractors have also facilitated the application of technologies originally developed for DoD applications for use in civilian education and training programs. Examples of this type of transfer include: (a) collaboration between the PLATO project and Control Data Corporation, which resulted in significant national investments by CDC and subsequent development and marketing; (b) early involvement of American Institute for Research and Department of the Army sponsorship of computer-managed instruction projects which subsequently contributed to the development and marketing of Project PLAN to school systems; (c) HumRRO's interactive videodisc developed for the Army, subsequently made available to medical education; and (d) WICAT's hardware technology developed in a DoD R&D program, one of the first to be used in civilian education and training.

Perhaps the most significant contribution of DoD to technology transfer has been through direct involvement of people. During the creation of the Job Corps, many of the key staff involved in educational technology, research, development, and demonstration were assigned from the DoD services; this contributed to many of the successful instructional programs subsequently used in the Job Corps. DoD also provided opportunities for key professional staff and civilian agencies to continue their R&D studies and development activities when civilian agency priorities changed (e.g., the number of staff which left NIE in the eighties to join AIR). Indeed, DoD agencies such as DARPA and ONR have often created specific communities of R&D focus within universities by funding principal investigators and graduate students, many of whom, after developing expertise and skills, sought employment or professional activities in civilian education environments.

IV. FACTORS CONTRIBUTING TO SUCCESSFUL FEDERAL RESEARCH AND DEVELOPMENT FUNDING FOR EDUCATIONAL TECHNOLOGY

The purpose of this section is to identify some of the factors that have contributed to successful Federal funding of research and development activities in the field of educational technology. In considering the question of what produces successful work in this field, it is useful to bring into focus certain distinguishing characteristics of the field itself. Four main characteristics are:

- Research and Development is involved with change; change in education is risky and threatening to the status quo.
- Research and development in education involves a very large, highly complex, and decentralized collection of interrelated institutions that are not only inherently resistant to change but also not under the direct authority of the Federal government or even the states.
- Research and development in educational technology is even more risky due to the very rapid changes in the technology base itself.
- The community of sponsors of this work at the Federal (and often performer) level has been small and close-knit, often resembling an "underground" movement.

Strategies for Federal funding support of educational technology research and development must take these key characteristics into account. In this section we group the factors, which contribute to successful R&D programs, into five categories, as follows:

A. Funding
B. Leadership
C. Strategic Planning for Innovation
D. Administration of Research and Development
E. Procurement Processes

A. FUNDING

We find six characteristics of funding for successful research and development in educational technology: amount of funding, continuity of support, interagency collaboration, cooperation with industry, flexibility of funding, and research mission.

First, the amount of funding support for a given project or program must be adequate for the type of research or development being undertaken. The hardware and software base needed for the research or development must be appropriate to the mission. In the Air Force, for example, the most important type of technology needed for training involves complex flight simulators which require highly sophisticated hardware and software. The Air Force spent $95 million dollars (or over 25 percent of the total DoD education and training R&D budget) in 1987 on such simulation research and development. To perform research on new kinds of applications of technology to education, such as Intelligent Tutoring Systems, requires a more sophisticated machine base than the kinds of machines now available in schools. On the other hand, a relatively small amount of dollars spent at the right time with the right people for a conference can make a major contribution to the state of the art. The amount of funding for a given project also must be viewed in relation to other projects within a program. At ONR, relatively small dollar funding was strategically placed with several projects in a thematic "cluster", thus creating a critical mass of work in an important new area.

As important as the adequacy and appropriateness of funding is the continuity of support for a program or project. Major innovations require eight to 15 years from their inception to reach commercial or widespread application. For example, research and development for LOGO began in 1967; the first commercial application occurred 14 years later in 1981. Successful program managers and project directors have been able to find ways to sustain funding for a project or line of inquiry over a period of several years.

One of the ways successful program managers have been able to sustain funding for promising research is by collaborating with their counterparts in other agencies. Some of the most successful projects have resulted, for

example, from joint efforts by the National Science Foundation and the Department of Education. During periods when budgets for civilian education have been cut, NSF program managers have protected their most important projects by seeking support from military agencies. DARPA has been a very important collaborator for many agencies. The Office of Naval Research has for many years taken a leadership role in bringing key program managers from various agencies together with researchers at conferences to share ideas and information about important developments in the field, thus facilitating interagency collaboration.

Another mechanism successful program managers have found for sustaining adequate funding for research and development is to establish cooperative funding with industry. When NSF lost its budget in 1982, program managers Molnar and Deringer set up an industry collaborative effort that resulted in the donation of millions of dollars worth of computing equipment for NSF research and development performers. As another example, during the sixties, IBM "loaned" a large number of 1500 System units to DoD agencies for evaluation and research purposes and many defense contractors contributed experienced staff to the creation of the Job Corps.

Flexible funding authority is another important characteristic of funding for educational technology innovation. To address key problems for which it is well suited, an agency must identify trends, events and circumstances that make its involvement timely. To take advantage of timely opportunities requires flexibility in the funding authority. NSF, for example, has considerable flexibility compared with other agencies in the way it carries out its mission. It can direct its funding toward the science education needs it identifies as most important. It can support grants or contracts; individuals, academic institutions, or corporate entities; conferences; research and development; training; recognition awards; or other activities. By operating directly through grants, the Science Education Directorate (SED) allows qualified grant recipients wide latitude to exercise their creativity. As an independent grants-making agency, NSF does not answer to any other department of government. It has the freedom, with the consent of the National Science Board, to pursue its own agenda and develop its own programs. Of course, SED is subject to policies of the executive branch,

public and Congressional demands, and the interests of its own constituency. In contrast, ED's funds are for the most part disbursed through formula-allocation block grants to states and localities and are earmarked for a particular type of activity. ED does have flexibility within a program authority (such as Special Education Programs, SBIR, the Secretary's discretionary fund, etc.) but it is hard to combine funds across authorities in a strategic manner.

Within ED, the only office with a direct mission to develop technology has been the Office of Special Education Programs (OSEP) through the captioned films program (and later the Media Services/Technology Program). Attempts to "demonstrate" technology in OEO during the 1960s and transfer technology initiatives from DoD to civilian use suffered from the lack of authority and mission.

B. LEADERSHIP

A review of the history of Federal funding for research and development in educational technology over the past three decades shows a clear pattern of leadership within the agencies that have made major contributions to the field. In most of the agencies examined, we find productive R&D associated with leadership at executive and program management levels. Where executive leadership has been lacking, we found dedicated program managers who have attempted to find creative ways of compensating for lack of high-level leadership.

At high levels, leaders encourage risk-taking and take initiatives in seeking funding appropriate to that risk-taking (e.g., the directive from Secretary McNamara in 1965, President Johnson's mandate creating the OCA at NSF in 1968). At ONR, top management has supported risk-taking, because the mission of ONR was basic research. The consequences of lack of high-level leadership have been seen in NSF, where the top management over the years has been at various times nonsupportive of science education in general, and/or educational technology in particular. At the Department of Education, executive management has been so highly politicized in recent years that

coherent long-term R&D strategies have been difficult to formulate and sustain.

At the program manager and division levels, successful work in each agency has resulted from the continuing efforts by dedicated civil servants with vision, persistence, and an emphasis on quality. These individuals view their jobs as shaping the direction of the emerging field and identifying strategic opportunities for innovation and improvement of learning and teaching through technology. They persist in supporting these thematic lines of research and development through the vicissitudes of funding authority, political and organizational change, and the changing technology base. Examples are Andrew Molnar at NSF; Glen Bryan and Marshall Farr at ONR; Dexter Fletcher and Harry O'Neill at DARPA; and Frank Withrow, Arthur Melmed, and Martin Kaufman at ED. These individuals also sought out and supported leaders in the research community who can contribute to advances in the state-of-the-art. These program level leaders view themselves as true colleagues of the research community, not just bureaucratic administrators. At ONR, for example, program managers keep close tabs on the field. They have an open door to early thinking from potential proposers, and can identify new opportunities and individuals who can contribute to advances in the state of art. Marshall Farr of ONR says, "We acted as if someone's life were at stake. If you're going to advance the state-of-the-art, nothing but quality will do."[71]

C. STRATEGIC PLANNING FOR INNOVATION

Support for cutting edge work in an emerging field requires strategic thinking, coordinating many dimensions of the work. An effective R&D strategy has the following components:

- an overall long-term goal, along with five- and ten-year objectives that represent steps toward the goal.
- a coherent set of initiatives, aimed at improving content and methods of curriculum; professional capacity of educators; and functioning of the overall educational system.
- a clear philosophy of change and the agency's relationship to it.

An example of a strategic initiative taken recently by the SED of NSF is the targeted solicitation (issued in 1985 with awards made in 1987) supporting the development of elementary mathematics programs that feature the calculator and the computer. It addressed a central conceptual and programmatic problem in K-6 mathematics (the organization of mathematics to reflect the impact of two key technologies), approached the problem in a way that was particularly appropriate to NSF (by inviting collaborative projects drawing on the mathematics education and mathematical sciences communities), and called for proposals at an opportune time (following a spate of reports calling for the reform of mathematics education, at a time when the two technologies were becoming widely dispersed in schools). Further, the initiative was practical; the implied philosophy of change -- aimed at long-term rethinking of the K-6 curricular base -- was appropriate to the state of knowledge and general progress toward reform goals.[72]

When research and development involve new technologies, there are many competing purposes and foci of attention. On the one hand, R&D can focus on specific needs in education such as: expanding the pool of competent and interested science learners or advancing scientific understanding of learning and teaching; or understanding better the cognitive processes of beginning readers. On the other hand, R&D can address advances in the technology itself (e.g. better graphics displays, communications networks). Most experienced participants in this field agree that research and development funds in educational technology are most productively and successfully spent in pursuit of strategic goals that focus on needs and opportunities in learning and teaching and scientific knowledge, rather than on technology-focused strategies. That is, the technology, the hardware and software, must be viewed as a means, a vehicle, and not an end in itself. This perspective led to the creation of OSEP's Media Service/Technology Program in the early eighties, and to its successful implementation.

Successful program managers take a long-range view of innovation. Andrew Molnar at NSF, for example, focuses on advanced technology that has promise of making orders-of-magnitude improvement in learning and teaching five to ten years from now. Although the funding level for the Advanced

Applications of Technology program is small (about $5 million), it is strategically invested in long-term payoff projects.

At the beginning stages of innovative research, there are few researchers competent to perform such work. Thus an important dimension of strategic planning involves finding ways to create a cadre of people within the research community who can perform the work. When ONR began funding research in Intelligent Computer-Assisted Instruction, for example, there were just a handful of researchers with appropriate backgrounds and interests who could do this work. Thus, ONR supported selected graduate students, thus growing their own experts. At NSF, the Science Education Directorate supports graduate students with fellowships (in science, not science education), but the fellowship program is not coordinated with the technology research program.

In order to make advances in a new area of research, development, or application of technology, there must be a concentration of work in that key area. Marshall Farr at ONR, for example, created thematic "clusters" of work in order to get a critical mass of research and researchers. Since the budget for educational technology research at any one agency is usually too small to create such a critical mass, coordination among agencies and industry can be critical.

An important ingredient of this critical mass of work, is an appropriate equipment base for the research community. But educational technology research and development programs rarely have the level of funding needed to provide such an equipment base. For his Advanced Applications of Technology program at NSF, Molnar insists that the hardware base for advanced development projects not be limited to the kinds of machines currently used in schools. Creating new software tools with potential to make an order-of-magnitude difference in learning and teaching requires use of the most advanced machine and software base possible. One mechanism Molnar developed was a cooperative program with the computer industry to provide such equipment to the research groups. At ONR, Marshall Farr and Henry Halff around 1983 took advantage of the Defense Research Instrumentation Program to set up an equipment network at

the Learning Research and Development Center at the University of Pittsburgh, involving Xerox Dandelion computers, for all ICAI contractors to use.[73]

Similarly, moving the outcomes of research and development into practice involves training and professional development of practitioners. The NSF has had teacher training programs, but these have not been coordinated in a strategic manner with their research and development programs. OSEP has a teacher training program coordinated with technology and related research and has supported the creation of Master's degree programs in special education technology at a number of leading universities.

Strategic planning involves appropriately timed basic research, applied research, development, demonstration and evaluation work. These do not usually follow a neat sequential pattern. Often, development or demonstration will result in deeper understanding of needed basic or applied research, or the need for new evaluation methods. Thus, flexibility in the research-development-test-evaluation paradigm must be available throughout a strategic program.

With the exception of some types of very basic research, educational technology research and development are most successful when they involve end users in naturalistic settings (e.g., school classrooms, DoD training commands). In a recent initiative by DDR&E to provide money for research and development in the military, each proposal must be supported by a military service command which agrees to field-test and use any resulting product that meets design/ performance specifications.[74]

D. ADMINISTRATION OF R&D PROGRAMS

The administration of an R&D program is influenced by a number of factors including its history, the political context of the time, mission, general agency administrative budgets, and personnel procedures and practices. While these factors differ among Federal agencies supporting R&D, a number of important characteristics are consistently evident in successful R&D programs.

1. Internal Reporting and Coordination

Effective internal communications, reporting, and coordination are important factors for any R&D program. For example, within the Media Services/Technology Program in ED/OSEP, staff participated in the development of the overall plan and communications were ensured through regular staff meetings and informal briefings. ED/OSEP's ability to ensure proper coordination among the various projects which supported, to varying degrees, technology R&D has led to a balanced R&D program in which most projects contributed to the overall plan. Unlike most agencies, OSEP has a history of high-level coordination among officials responsible for research and development, training, and program implementation directed at users. Within ONR, communications take the form of project briefings and and staff workshops. Coordination and communication needs within the NSF program were minimal because it was, in essence, a one-person operation.

2. External Communications

Communications with performers, the R&D community, and other groups have been very critical in most successful programs. Virtually all successful programs have relied heavily on agency-sponsored conferences, workshops, and symposia and have provided opportunities for agency staff to interact with their R&D communities. A particular strength of the DARPA program, for example, has been the close personal and collaborative relationships among program managers, researchers, and the R&D communities which they support. Availability of ARPANET certainly has facilitated informal communications, sometimes at the expense of traditional means of scientific knowledge building through journals and other publications. ONR's history of funding conferences, workshops, and state-of-the-art surveys has been significant in fostering effective communications, as has been the Annual Software Conference and R&D Symposium for OSEP's Media Services/Technology Program. In most successful agencies, staff restrictions (e.g., travel) have been overcome through contractor-sponsored conferences and meetings and by informal means of communication. Beyond communications with performers in the R&D communities, a major strength of the OSEP program has been its information dissemination

activities with users, the private sector, and Congressional staff who advocate technology use in special education.

3. Management Styles

Although management styles in administering successful R&D programs have varied considerably from agency to agency, there appears to be one ingredient common among them -- flexibility for R&D professionals to pursue areas of scientific inquiry in house or with key members of the R&D community in accordance with professional, rather than administrative and political, standards. In a fast-changing, technology-based field of endeavor, it is important to have flexibility in management that enables decisions to be made quickly. Agencies vary greatly on this dimension. For example, DARPA and NSF jointly created a program for college students to design VLSI circuits and have them physically fabricated by DARPA. DARPA was able to authorize the program in an afternoon; it took NSF six months to approve the program.

4. Staff Roles and Continuity

Professional staff in different successful programs have played various roles appropriate to the programs' goals. For example, in the basic research area, agencies such as DARPA draw professionals from the R&D community who continue to work with that community in a collaborative manner. While such collaboration occurs during the initial phases of ED/OSEP technology grant programs, continued collaboration is often constrained after projects are initiated. In its directed research and development projects, OSEP's Media Services/ Technology Program collaborates with potential performers in research design and, in many cases, throughout conduct of the research.

Staff continuity is also important, but takes different forms. In DARPA, for example, although program directors have a relatively high rate of turnover, the staff come from and usually go back to the research community of interest, thus fostering continuity of ideas and inquiry (if not individual roles). Continuity of staff within OSEP's Media Services/Technology Program has been quite high over the last decade; however, the recent, untimely death of the branch director, Dr. James Johnson, and anticipated other staff

turnover could disrupt that continuity. The impact of these changes on the program, along with the creation of a separate legislative authorization, will be interesting to follow in the next year.

A mix of two kinds of staff ingredients are important: highly competent professional, long-term civil servants mixed with short-term expert "rotators" from the field. Dedicated staff with vision and a long-term commitment to the purposes of educational technology are essential in an agency wishing to advance the state-of-the-art. ONR, for example, had very low staff turnover during the 1970s and early 1980s. Marshall Farr at ONR insisted on hiring and keeping highly qualified people. The staff was encouraged to participate actively in the field. The staff were considered fellow scientists by the field, not bureaucrats. Since the staff were respected as colleagues by the field, a great deal of informal and timely information exchange could take place. At NSF, Andrew Molnar has played a similar role, although not always with the support of higher management.

The conditions for hiring and keeping highly qualified staff who perform as professionals in the field include such things as: travel funds and encouragement to attend professional meetings and conferences and site visits, time for writing professional papers, and policies that encourage potential proposers to visit the offices and discuss draft ideas with the staff. ONR has sponsored annual meetings of contractors in a thematic area, at which the staff would have ample time for discussion with senior researchers and key staff people from other agencies. DARPA has attracted top-notch people from the field by offering flexibility to make an impact on the developing field and by keeping administrative paper work to a minimum. Within the Department of Education, these conditions have been met less and less. NIE created Excepted Positions (rotators from the field) to attract good people, but these positions, according to some observers, have become politicized.

5. Organizational Climate

The organizational climate in which an R&D program is administered can have a significant impact on the success of the R&D technology support. It is interesting to note that, within the Department of Defense, relationships

between the R&D agency (e.g., ONR) and the parent organization (e.g., the Department of Navy) have often been strained. The AAT program which supported most of NSF's educational technology R&D had similarly strained relationships with the NSF Board and management hierarchy. In the cases of ONR, during the sixties and seventies, strong leadership, a tight program with justifications, and successful projects (all of which appear to have been interrelated) evolved. During the sixties at the Office of Economic Opportunity, the organizational climate, even though somewhat chaotic, was conducive to high-risk R&D activities and successful demonstrations of technology outside the traditional school environment. During the early seventies, however, the climate changed almost overnight as OEO was abolished and NIE was created. This negative climate tended to affect the environment in which NIE supported R&D for technology and contributed to low morale and high staff turnover during the 1980s.

Generally, the organizational climate within which educational technology R&D programs existed had not been conducive to quality programs. Without high-level organizational support, the educational technology R&D programs and performers have tended to remain in an "underground" mode.

E. PROCUREMENT PROCESSES

The procurement process used by agencies is their primary formal means of establishing relationships with the R&D community. Research and development cannot be procured in the same way as nuts and bolts. The mechanisms must make it possible to attract the most highly qualified performers and enable them to carry out the work in a creative, sustained manner. While the issues are usually very complex, there appears to be certain elements in the procurement process which are associated with successful R&D programs.

1. Instruments

In general, <u>successful R&D programs have the flexibility to use different types of procurement instruments for different types of performers and types of R&D</u>. Observers agree that, in most instances, grants are most

appropriate for unsolicited, field-initiated, and similar types of basic and some applied research areas; contracts tend to be most appropriate and effective in directed development, demonstration, and related projects. Generally, grants have been used to support not-for-profit and university performers, while contracts have been used extensively with private firms. OSEP's Media Services/Technology Program, through its various programs, has used grants, contracts, and cooperative agreements. Because over 90 percent of its research performers are universities or nonprofit organizations, the NSF program makes extensive use of grants. Recent NSF initiatives to involve commercial firms -- potential publishers and distributors of R&D products -- has resulted in an increased use of contracts. Use of fixed price contracts for R&D under the Small Business Innovative Research program (used extensively by the Media Services/Technology Program) appears to have contributed to successful R&D efforts and has reduced paper work.

2. Solicitation Process

Successful R&D programs are usually characterized by solicitation processes that are not constrained by agency administrative procedures and that ensure a clear understanding about desired products or services on the parts of appropriate individuals and organizations within the R&D community. Most formal solicitations take the form of grant announcements, usually preceded by listings of priorities in the Federal Register, and/or Requests for Proposals.

Agencies have used different means of informal solicitation. The Media Services/Technology Program has made extensive use of informal meetings and conferences as a basis for soliciting input from the R&D community, as well as a means of communicating priorities. During the 1960s and 1970s, DARPA relied heavily on personal solicitations on ARPANET and through other means of personal communications between DARPA staff and key performers. ONR relies on informal discussions with potential performers which help shape the direction of proposals. In the mid-seventies, senior ONR research staff wanted to computerize a testing system based on the "latent traits" theory. When the developer of the concept declined to participate, ONR "put the word out" that they were interested in anyone familiar with the senior scientist's research

on "latent traits" and that ONR would fund computerization of the testing procedures. After numerous discussions, a proposal was submitted and a system was developed. NSF traditionally has asked for proposals from the field through broad program announcements such as the current "Instructional Materials Development" program.

3. Length of the Procurement Process

The length of the procurement process in many agencies has often been detrimental to the agencies' R&D programs. Successful R&D programs have undertaken several initiatives to minimize this impact. OSEP's Media Services/Technology Program, for example, has funded development projects of relatively short durations in an attempt to minimize technological obsolescence and has made use of minority set-aside awards which can bypass the traditional, lengthy ED procurement process. During the sixties and seventies, DARPA used its existing -- relatively efficient -- contracting procedures or worked out informal relationships with contracting agencies in the services to ensure high contracting priority for these DARPA-supported projects. NSF at one time relied heavily on the lengthy peer review process. However, in its collaborative efforts with the Department of Education, a joint panel (providing continuity of key reviewers) now reviews technology-based R&D projects and has tended to reduce the length of NSF's procurement process.

4. Review Criteria

Peer review has been useful for programs where the intent is to allocate resources fairly within a community. It is also useful for screening out flawed proposals. But it is not helpful if the intent is to support innovation, new paradigms, and concentration of work within a thematic area. For example, it is extremely difficult to get multidisciplinary or interdisciplinary work funded through peer review panels whose members have a stake in the infrastructure of existing disciplines. In education, it is difficult to get advanced technology work funded through peer reviewers who insist on using machines that are already installed in schools. In the

military, when technology R&D proposals are reviewed by people responsible for training operations, it is difficult to fund any really risky projects.

F. SUMMARY: FACTORS CONTRIBUTING TO SUCCESSFUL FEDERAL R&D FUNDING FOR EDUCATIONAL TECHNOLOGY

Research and development in educational technology is, by definition, involved with change and innovation in a complex and rapidly advancing technological environment. Major innovations require many years to reach fruition. The work requires advanced state-of-the-art equipment and software bases and correspondingly knowledgeable performers.

The characteristics of funding agencies and programs which lead to successful R&D, then, correspond to the characteristics of the work. Funding support should be appropriate to the task, continuous over a period of several years, and flexible enough to adapt to changing circumstances. Leadership is exercised at both executive and program levels, by dedicated staff with vision and colleagueship within the field.

Strategic planning takes into account long-range educational needs and opportunities for advancing scientific understanding of learning and teaching. It considers the need to build a cadre of expert, multidisciplinary performers of the work, and the corresponding need for a critical mass of work in the strategic area. It adapts to changing technology base, appropriate timing of basic and applied studies, demonstrations, and evaluations.

Administration of the work requires informal mechanisms for internal and external communications; flexible management styles; continuity of highly competent, dedicated staff mixed with short-term rotators from the field; and an organizational climate conducive to risk taking. Procurement instruments and processes need to be flexible so that the most appropriate methods are available for the type of work to be accomplished.

V. POLICY RECOMMENDATIONS

In this section we discuss policy recommendations in the context of: (a) the role of the private sector, and (b) the issues of the 1980s.

A. CHANGING CONTEXT AND ISSUES IN THE EIGHTIES

While the historical context of education technology R&D and the role of the private sector during the decade of the eighties have differed significantly from that of the 1960s, some of the issues remain while new ones have surfaced.

1. Role of Industry

During the sixties, fewer than 20 major organizations were the major actors in the computer-based education movement. TALMIS[75] estimated that, by the early 1980s, the number of software producers and publishers were close to 600. Although the total number of software developers/publishers has declined slightly, half of the educational software sold to the schools in 1986 can be attributed to approximately 25 firms. As a side effect of the Tax Reform Act of 1986, a significant number of small to medium-sized software producers and publishers were acquired; this has resulted in a considerable increase in the degree of concentration of the primary producers of educational software products. During the 1960s, IBM, with its 1500 System, was highly visible in computer-based education; today it is joined as a primary hardware vendor in education by Apple, Commodore, Tandy, and other producers of "look alikes" -- companies that did not exist 25 years ago.

In the 1960s, R&D in educational technology was largely Federally supported, much of it by the Department of Defense. An exception was the IBM Corporation, which funded a number of CAI development centers. During the late 1970s and early 1980s, most of the educational software R&D and virtually all of the hardware development were conducted by the private sector, usually without direct Federal support. An exception to this trend has been the Minnesota Education Computing Consortium (MECC) which has received state and

Federal funds. During the 1980s, most firms (particularly software developers) have been small to medium sized; only a few (e.g., The Learning Company, MECC) received Federal support directly or indirectly.

Unlike the 1960s, when computer-based education products relied on mainframe, time-shared systems, during the early 1980s the primary focus was stand-alone microcomputers used initially for programming and supplemental basic skills instruction (CAI) and subsequently for tool applications. Only in the last three years have local area network configurations emerged in the schools. Unlike the 1960s, when joint ventures between electronic contractors and publishing firms (including many defense contractors) attempted to enter the education market relying on the "systems approach", during the early 1980s most of the publishers attempted to develop software products to meet existing perceived market needs.

2. Public Policy Issues

Unlike the 1960s' top-down approach to education technology R&D support, fostered by reform-minded Federal officials within the Office of Education, National Science Foundation and Department of Defense (including many public officials who later became chief executives of private sector technology ventures), during the 1980s the microcomputer phenomenon was essentially a bottom-up phenomenon generated at the grass roots. With the exceptions of a limited number of development efforts sponsored by the Department of Education (OERI), NIE, and NSF, official Federal policy formulation was minimal (although a number of Federal initiatives -- such as SLATE --were undertaken to help states formulate policies). Prior to 1981, only seven states had formal policies related to education technology; within a year or so, more than 40 additional states had developed such policies. This reflected the increasingly pivotal role states began to play in the emergence of electronic learning technology. In recent years, a number of states -- independently or through interstate consortia -- have organized several large-scale research and development projects relating to computer use, software evaluation, and telecommunications -- efforts which were supported in spirit by the National Governors' Association report "Time for Results".

The public domain policy issues of Federal agencies, evident during the 1960s, has not surfaced during the 1980s largely because copyright and license policies within agencies are now more flexible and because only small development efforts being funded. However, the issues of unauthorized copying and copyright protection for publishers arose early during the 1980s and remain an issue today.

During the 1960s, computer-based education was almost universally assessed against cost-effectiveness criteria. Only recently have policy makers at the local and state levels begun to raise such questions again. The issues of centralization and curriculum control, important during the 1960s, have not emerged significantly during the 1980s, but are manifest in such related issues as: (a) the increasing role of states in technology planning, particularly as influenced by the rapid development of telecommunications technology; (b) national debates on what should constitute "computer literacy" (i.e., programming versus tool applications); and (c) the need to integrate computers into the curriculum versus the reform of curriculum to prepare students for the information age. Unlike the 1960s, when organized teacher groups were usually (and sometimes vehemently) opposed to technology because teachers were concerned about being replaced by computers, during the 1980s teacher organizations (e.g., NEA, AFT) have increasingly supported computer use, particularly as tools to increase teacher productivity and to supplement basic instruction, particularly with low-achieving and special education students.

B. RECOMMENDATIONS

Within the changing context described above and considering factors contributing to successful R&D programs, below are highlighted recommendations which would improve the quality of Federal R&D support for education technology. These recommendations include: (1) legislative initiatives and oversight; and (2) executive branch administration.

1. Legislative

As Congress considers legislation creating, expanding, or amending support for Federal R&D programs for education technology, it should ensure that the following provisions are included:

- The mission of an R&D program which supports education technology should be clearly stated.
- Authority should be appropriate to the mission, with flexibility to use appropriate procurement instruments with a variety of performers.
- To ensure program continuity, provisions should shield the R&D program from the vagaries of the political process.
- Mandated R&D programs should have direct access to department heads.
- The amount of funding appropriated for a given program must be adequate for the type of R&D undertaken and provisions should be made for continuity of funding support.
- Provisions encouraging interdepartment and/or interagency coordination of funding and other types of R&D support should be explicit to maximize impact and minimize unintended duplication of effort.
- Agencies should be required to justify R&D program goals and objectives -- based on demonstrated needs, problems, or unique opportunities -- on a continuing basis and appropriate funding and other support should be provided for this purpose.
- R&D programs should be encouraged, if not required, to collaborate with the private sector R&D community and/or other non-Federal sponsors such as foundations and state departments of education.
- While the mission of an R&D program should be clear in the legislation, the funding authority must be flexible enough to take advantage of unique opportunities, advances in technology, and windows of opportunity to collaborate with other agencies.
- Each R&D program should be required to establish and implement mechanisms (including "rights and royalties" policies) through which the resulting products of the R&D program can be effectively and efficiently transferred to appropriate users within the education community. Specific funding should be earmarked for these purposes, including demonstrations of resulting products in naturalistic settings. In those R&D programs where a secondary objective is to encourage technology spin-offs (e.g., from the DoD education and training to civilian education and training), legislative programs for that purpose should be established with appropriate funding levels.

2. Executive Administration

A number of recommendations relate primarily to the administration of Federal R&D support for education technology and are applicable to most, if not all, of the agencies addressed in this study (e.g., Department of Education, Department of Defense, National Science Foundation).

a. Leadership

Strong leadership is required at both the department/agency level and the program level. While the nature of department/agency level leadership will vary, it must focus on one or more of the following functions: (1) establishing and communicating priorities for R&D support; (2) generating support within Congress and the R&D community; or (3) encouraging risky, but high potential payoff, R&D while minimizing jeopardies to the careers of administrative staff and performers. Such leadership at the R&D program level should: (1) ensure adequate administrative support for R&D performers; (2) provide appropriate incentives for quality R&D; and (3) create and maintain an organizational climate conducive to quality R&D performance and appropriate levels of risk taking.

A strategic plan for innovation should be developed for each major program supporting "cutting edge" R&D. This strategy should include: (1) an overall, long-term goal with at least five-year objectives representing steps toward the goal; (2) a coherent and coordinated set of initiatives including technology development to improve content, instructional delivery, dissemination/distribution, and support activities (including training) to implement technology use; and (3) a philosophy of change in the R&D program's relationship to projected functioning of the overall education system. Where appropriate, strategic plans should also include components which relate to and take into account private, state, and other non-Federal initiatives, plans, and projections related to technology use in education.

b. Program Administration

Each R&D program should have established procedures for internal coordination and for communication with other offices involved in related R&D, capacity building, staff training, and user implementation. In addition, effective external communication procedures should be established to: (1) communicate priorities and solicit proposals from the R&D community; (2) facilitate collaboration between program staff and performers; (3) disseminate findings to the R&D community; and (4) provide opportunities for feedback from potential users. Administrative leadership should also provide flexibility for R&D professionals to pursue areas of scientific inquiry in-house or with key members of the R&D community in accordance with professional rather than administrative standards.

c. Staff Continuity

As noted earlier, continuity of staff within the agency and R&D community is critical to successful long-term, high-payoff R&D. Two kinds of highly competent professionals should be involved -- long-term civil servants and short-term expert "rotators" from the performing R&D community. Agency personnel policies should be reviewed to ensure that rotators can be hired for specific terms and/or projects and that rotators are selected and hired on the basis of professional contributions rather than for political and other reasons. Agency staff should also be provided with necessary travel, equipment, and other support which will contribute to the program's overall mission and their professional growth within the R&D community.

d. Procurement Process

Traditional procurement procedures used with weapons systems and such equipment are neither efficient nor effective as a means of supporting educational technology research and, in most instances, development. Agencies should review their existing procurement procedures to ensure that the programs attract the most highly qualified performers and enable them to carry out the work in a creative manner. R&D programs should have the flexibility to use different types of procurement instruments for different types of

performers and different types of research and development. The use of the Small Business Innovative Research program should be relied on to the maximum extent for the development of technology applications in education. While "solicitation" procedures may vary from agency to agency and among programs, they should be both effective in communicating priorities for unsolicited proposals and performance based with respect to directed R&D to ensure inclusion of the latest advances in technology. Each agency should review existing procurement procedures to ensure that the length of the process does not result in out-of-date statements of work due to technology advances. For each R&D program, there should exist opportunities for "peer review" either in: (1) establishing program priorities for R&D; (2) reviewing proposals, particularly unsolicited or field-initiated; (3) the use of advisory committees in directed R&D; or (4) other forms of informal peer input through symposia, conferences, etc. involving agency staff and members of the R&D community.

References

1. Defense Industry Bulletin, July 1966, p. 13.

2. Office of the Secretary of Defense, Manpower; Background paper for CTEP: Training Methods Study, 1966.

3. Secretary Robert S. McNamara, U. S. Department of Defense, Memorandum August 16, 1965.

4. Office of the Secretary of Defense, Manpower, CTEP: Training Methods Study (Washington, D.C.: 1966).

5. Office of the Secretary of Defense, Manpower; Background paper for CTEP: Training Methods Study, 1966.

6. Gabriel D. Ofiesh, "Educational Technology in the Air Force", American Behavioral Scientist, November 1962, p. 62.

7. Francis Keppel, "The Business Interest in Education", Phi Delta Kappan, January 1967, p. 186.

8. Fred M. Heddinger, "Will Big Business Control R&D?", Phi Delta Kappan, January 1967, p. 215.

9. Michael W. Kirst, (ed.), The Politics of Education at the Local, State, and Federal Levels (Berkeley, CA: McCutcheon Publishing Company, 1970).

10. Lawrence P. Grayson and Janet B. Robbins, U. S. Office of Education Support of Computer Projects, 1965-1971 (Washington, D.C.: U. S. Department of Health, Education and Welfare, 1972).

11. Ibid.

12. Louis R. Bright, Office of Education Support for Educational Technology (Washington, D.C.: U. S. Department of Health, Education and Welfare, 1966).

13. Andrew R. Molnar and Beverly Sherman, U. S. Office of Education Support of Computer Activities (Washington, D. C.: U. S. Department of Health, Education and Welfare, January 1969).

14. Andrew A. Zucker, "Support of Educational Technology by the U. S. Department of Education: 1971-1980", Journal of Educational Technology Systems, Vol. 10, No. 4, 1982, pp. 303-320.

15. TALMIS, Annual Survey of Microcomputer Use in Schools (New York, NY: 1982, 1983, 1984, 1985, 1986).

16. Education TURNKEY Systems, Inc., Presentation at IBM Third Party Publishers Conference (Rye Town, NY: June 1986).

17. Michael S. Knapp, et al., The Education Block Grant at the Local Level: The Implementation of Chapter 2 of the Education Consolidation and Improvement Act in Districts and Schools, (Menlo Park, CA: SRI International, January 1986.

18. Susan S. Klein, Computer Education: A Catalog of Projects Sponsored by the U. S. Department of Education, 1983 (Washington, D. C.: National Institute of Education, April 1984).

19. Charles A. Darby, Jr., et al., A Survey of Computing Activities in Secondary Schools: Final Report (Silver Spring, MD: American Institutes for Research, 1970).

20. W. J. Bukoski and A. L. Korotkin, Computing Activities in Secondary Education (Washington, D. C.: American Institutes for Research, 1975).

21. Beverly Hunter, et al., Learning Alternatives in U. S. Education: Where Student and Computer Meet (Englewood Cliffs, NJ: Educational Technology Publications, 1975).

22. Henry J. Becker, School Uses of Microcomputers: Reports from a National Survey (Baltimore, MD: The Johns Hopkins University, Center for Social Organization in Schools, 1984).

23. D. K. Deringer and Andrew R. Molnar, "University, Industry, Federal Cooperation -- A Case Study", Science, Technology, & Human Values, Vol. 8, No. 4, 1983, pp. 40-45.

24. Ibid.

25. Andrew R. Molnar, "Intelligent Tutors and Knowledge-Based Systems in Education", (Washington, D. C.: Paper presented at the Conference of Applications of Artificial Intelligence and Expert Systems, 1986).

26. Henry J. Becker, Instructional Uses of School Computers: Reports from the 1985 National Survey (Baltimore, MD: The Johns Hopkins University, Center for Social Organization in Schools, 1985).

27. M. S. Knapp, et al., Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation. Summary Report (Washington, D. C.: National Science Foundation, Contract No. SPA-8651540, 1987).

28. R. G. Gillespie (Chairman), et al., A Strategic Planning Approach for the National Science Foundations Applications of Advanced Technology Program (Washington, D. C.: National Science Foundation, unpublished manuscripts, 1986).

29. Ibid.

30. Andrew R. Molnar, personal interview with Beverly Hunter, July 1987.

31. Sylvia R. Mayer, "Computer-Based Information and Instructional Systems", Proceedings of the Engineering Systems for Education and Training Conference,

(Arlington, VA: National Security Industrial Association, June 1966), p. 141.

32. J. Dexter Fletcher and Marty R. Rockway, "Computer-Based Training in the Military", Military Contributions to Instructional Technology (New York, NY: Praeger Publishers, 1986) p. 177.

33. Ibid., p. 177.

34. F. E. Guinti, Computer-Assisted Instruction (CAI): U. S. Army Effects Part-Present-Future?", Briefing for TRADOC staff (Fort Monroe, VA: Army Training and Doctrine Command, Training Development Institute, April 8, 1980).

35. Fletcher, op. cit., p. 183.

36. Ibid.

37. Ibid., p. 211.

38. Ibid., p. 213.

39. Ibid., p. 199.

40. Guinti, op. cit.

41. Fletcher, op. cit.

42. Ibid., p. 180.

43. Ibid., p. 196.

44. John H. Rubel, personal correspondence to Sargent Shriver, April 14, 1964.

45. Economic Opportunity Act of 1964, Public Law 88-452, Section 207, 88th Cong., August 20, 1964.

46. Stanley Salette, personal interview with Charles Blaschke, July 1987.

47. Ibid.

48. Fletcher, op. cit., p. 206.

49. Ibid., p. 206-207.

50. Ibid., p. 207.

51. Ibid., p. 208.

52. Marshall Farr, personal interview with Charles Blaschke, August 1987.

53. Paul Chatelier, personal interview with Charles Blaschke, July 1987.

54. Education TURNKEY Systems, Inc., Survey of Microcomputer Use in Special Education (Falls Church, VA: February 1986.

55. Dr. Frank Withrow, personal interview with Charles Blaschke, August 1987.

56. Robert K. Yin, et al., Goal Evaluation of the Media Services/Technology Program (Washington, D. C.: COSMOS Corporation, September 1986), pp. 5-6.

57. Ibid., p. vi.

58. Ibid, p. vii.

59. Ibid., p. 55.

60. Judith Wilson, personal interview with Charles Blaschke, July 1987.

61. Susan Elting, personal interview with Charles Blaschke, September 1987.

62. Yin, op. cit., p. 58.

63. Wallace Feurzeig, "LOGO Lineage", Digital Deli, 1984.

64. Wallace Feurzeig, unpublished memorandum, December 1981.

65. National Science Foundation Program Announcement, Computing Activities in Education (Washington, D. C.: 1969).

66. Bolt, Beranek & Newman Report No. 2165, June 1971.

67. Daniel Watt, "LOGO In the Schools", BYTE, August 1982, p. 117.

68. Ibid., p. 134.

69. Dr. William Pierce, personal interview with Charles Blaschke, July 1987.

70. Chatelier, op. cit.

71. Farr, op. cit.

72. SRI International, Program Descriptions: Formal and Informal Science Education, Primarily at the K-12 Level (Washington, D. C.: National Science Foundation, Science and Engineering Education Directorate, 1986, p. 29).

73. Farr, op. cit.

74. Jesse Orlansky, personal interview with Charles Blaschke, July 1987.

75. Anne Wujcik, personal interview with Charles Blaschke, July 1987.

BIBLIOGRAPHY

Abelson, H., "A Beginner's Guide to LOGO", BYTE, Vol. 7, No. 8, pp. 88-112.

Fletcher, Dexter, Intelligent Training Systems in the Military, in press.

Knapp, M. S., et al., Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation, Volume 1 (Washington, D. C.: National Science Foundation, Contract No. SPA-8651540, 1987).

LOGO Group, Bibliography of LOGO Memos Available for Distribution (Cambridge, MA: Massachusetts Institute of Technology, Artificial Intelligence Laboratory).

National Science Foundation, Program Funding History: 1952-1985 (Washington, D. C.: National Science Foundation, Science and Engineering Education Directorate, 1986).

National Science Foundation, Summary of Grants, FY 1984-1986: Applications of Advanced Technologies Program (Washington, D. C.: National Science Foundation, Directorate for Science and Engineering Education, 1987).

National Science Foundation, Summary of Grants, FY 1984-1986: Instructional Materials Development Program (Washington, D. C.: Ntional Science Foundation, Directorate for Science and Engineering Education, 1987).

National Science Foundation, Summary of Grants, FY 1984-1986: Research in Teaching and Learning Program (Washington, D. C.: National Science Foundation, Directorate for Science and Engineering Education, 1987).

Papert, S., and Solomon, C., Twenty Things To Do With A Computer (Cambridge, MA: Massachusetts Institute of Technology, Artificial Intelligence Laboratory, 1971).

Papert, S., et al., Final Report of the Brookline LOGO Project: Project Summary and Data Analysis (Cambridge, MA: Massachusetts Institute of Technology, Artificial Intelligence Laboratory, AI Memo No. 545, LOGO Memo No. 53, 1979).

Syracuse university LOGO Project, Report No. 2: Progress Report: August 1972 (Syracuse, NY: Syracuse University, August 1972).

Tinker, R., "LOGO's Limits: Or Which Language Should We Teach?", HANDS ON!, Vol. 3, No. 1, pp. 1, 4-6.

Weir, S., and Watt, D., "LOGO: A Computer Environment for Learning-Disabled Students", The Computing Teacher, Vol. 8, No. 5, 1980-81, pp. 11-19.

Williams, G., "LOGO for the Apple II, the TI-99/4A, and the TRS-80 Color Computer", BYTE, Vol. 7, No. 8, 1982, pp. 230-290.

APPENDIX A

Interviewees/Information Sources

Mr. John Amos
Dr. Karen Billings
Mr. Paul Chatelier
Ms. Susan Elting
Dr. Marshall Farr
Mr. Wally Feurzeig
Dr. Dexter Fletcher
Mr. Ray Fox
Dr. Ed Fuentes
Dr. Henry Halff
Dr. Ted Hasselbring
Mr. Al Hickey
Dr. Martin Kaufman
Dr. Harvey Long
Dr. Andrew Molnar
Dr. Patricia Morrissey
Mr. Frank Moses
Mr. William Nelson
Dr. Harry O'Neil
Dr. Jesse Orlansky
Dr. William Pierce
Dr. Lois Richards
Mr. Stan Salette
Mr. Ron Saunders
Cdr. Alan Sears
Dr. Robert Seidel
Dr. Arthur Sheekey
Mr. James Stedman
Dr. Byars Vicino
Dr. Dan Watt
Dr. Frank Withrow
Dr. James Young

Correspondence

Mr. Art Barber
Dr. Harvey Brudner
Mr. Peter Drucker
Dr. Eugene Fubini
Dr. Marvin Kahn
Dr. Glen Mueller
Mr. Tom Padden
Dr. John Rubel
Mr. Peter Schruth